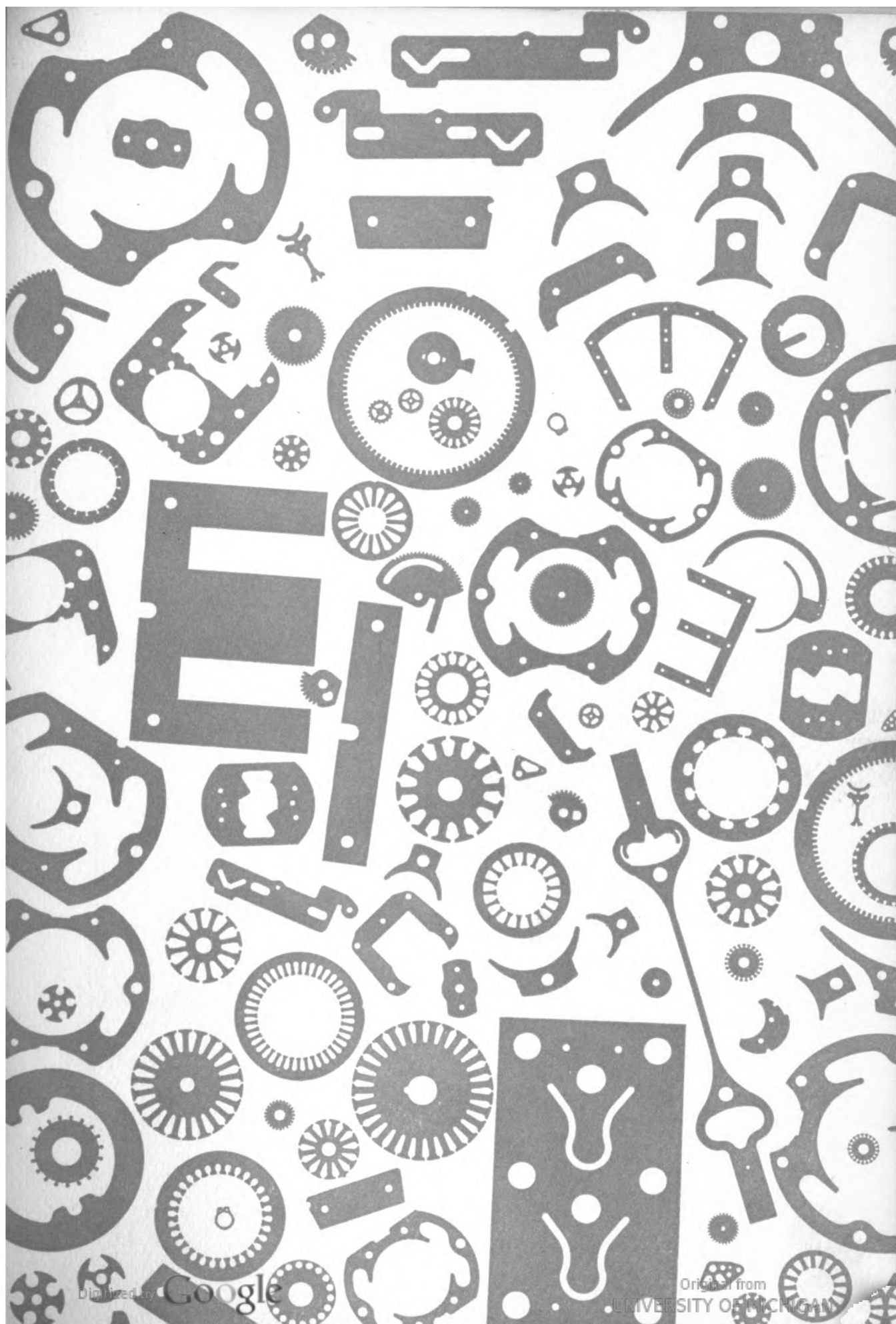


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*Located,*  
*Machined,*  
**HOLES, CONTOURS AND SURFACE**  
*Ground*  
*and Inspected*  
*by Precision*  
*Methods*

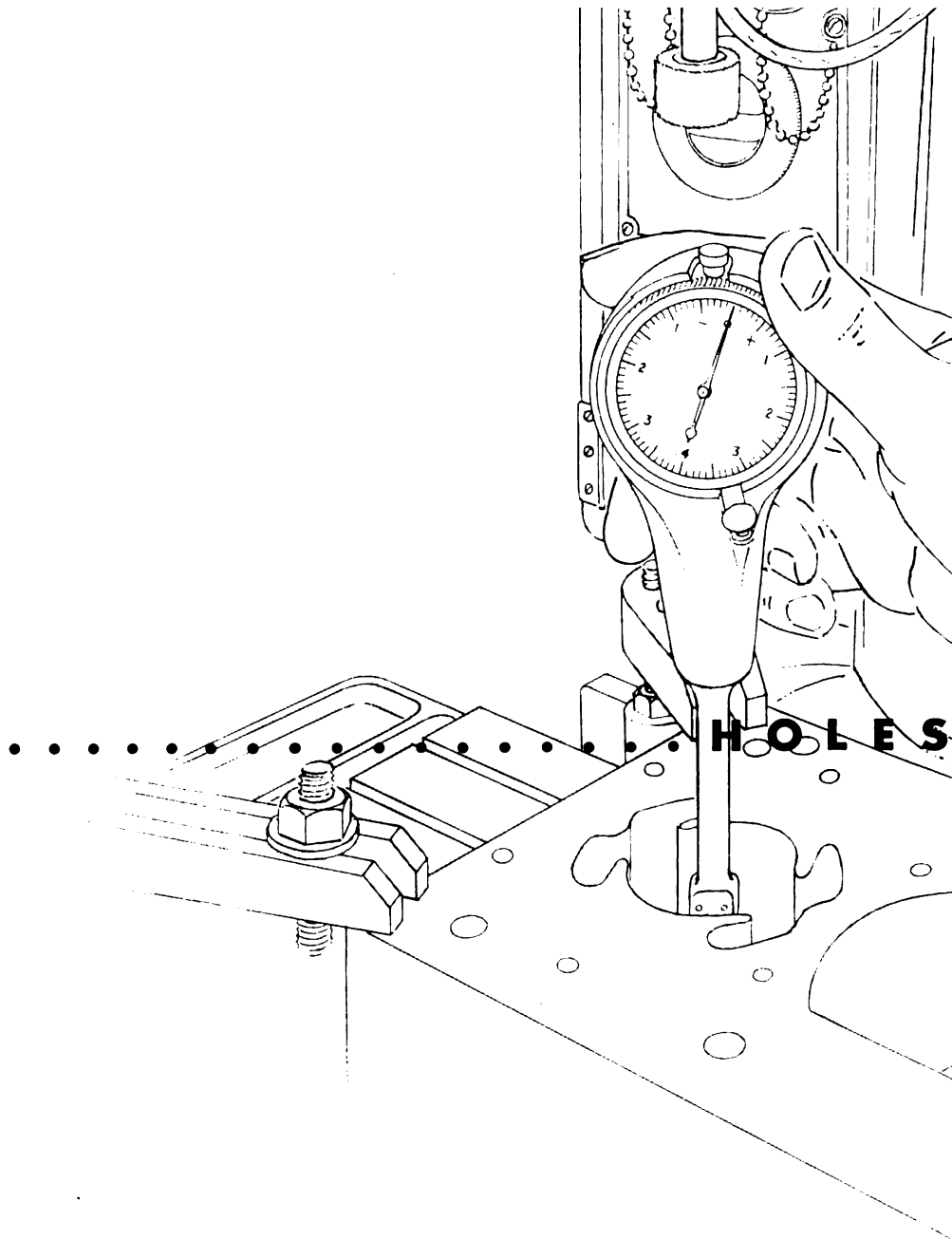








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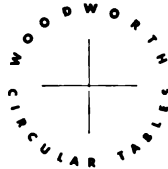
*Published by*  
**THE MOORE SPECIAL TOOL COMPANY**  
*Bridgeport, Connecticut*

*Richard F. Moore • Frederick C. Victory*

# **C O N T O U R S   A N D   S U R F A C E S**

*Located, Machined, Ground  
and  
Inspected by Precision Methods*

**I N C L U D I N G   W O O D W O R T H   C I R C U L A R   T A B L E S**



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## P R E F A C E

**I**N THE execution of "*Holes, Contours and Surfaces*," the authors have had the great advantage of starting with the material available in the pioneering book entitled "*Precision Hole Location for Interchangeability in Toolmaking and Production*," published by The Moore Special Tool Company in 1946 and enthusiastically received in the metalworking industry. Now out of print, this was the first authoritative book ever published on this vital phase of toolmaking.

Since the publication of that volume, the techniques of precision location have been extended from holes to contours and surfaces. There have also been many other major developments, including measurement and inspection techniques. These advances are fully described for the first time in this book.

The authors are indebted to the following companies, organizations and institutions for their cooperation in providing source material: American Bosch Arma Corporation; B and E Tool Company; University of Chicago; Allen B. Du Mont Laboratories, Inc.; Eastman Kodak Company; The Gaertner Scientific Corporation; General Electric Company; Gillette Safety Razor Company; Harig Manufacturing Corporation; Hilger & Watts Ltd., England; I-T-E Circuit Breaker Company; Koller Die & Tool Company; The Lux Clock Manufacturing Company; Lycoming Division of Avco Manufacturing Corporation; National Physical Laboratory, England; Remington Rand Inc.; Robbins & Myers, Inc.; Taylor, Taylor and Hobson, Ltd., England; Tippet Jig Bore Company; Victor Adding Machine Company.

We are also grateful to the following for reviewing parts of the book and giving us the benefit of their experience and advice: Fred Dingelstedt, of the Sperry Gyroscope Company; Burnham Finney, editor, and John P. Wright, associate editor, of American Machinist magazine; Mrs. C. E. Arregger, development engineer, of Hilger & Watts Ltd.; R. H. Cunningham, Jr., Albert Johnson, George Lamb, Jr., Anto Lindberg, Richard Parnoff, Herbert Randlette and Edward Shaw, Sr., all of The Moore Special Tool Company.

To Matt Farrell and his associate, William McAleer, goes credit for most of the photography in the book. Philip Segneri has also made important photographic contributions. The wash and line drawings are practically all the work of F. R. Gruger, Jr., and his staff. Styling, typography and printing were executed by George G. Adomeit and his associates at The Caxton Company.

Fred Wittner and staff at Fred Wittner Advertising supervised the entire publishing project.

RICHARD F. MOORE — FREDERICK C. VICTORY



*Complex products of modern mass production. Engineered locating equipment helps the manufacturers of such products to achieve greater accuracy and efficiency in toolmaking as well as on the production line.*

## I N T R O D U C T O R Y

**M**ODERN technology has advanced at so rapid a pace during recent years that fundamental processes are in danger of being overlooked. Automation holds the spotlight, and basic skills are being transferred from the man to the machine to such an extent that it might appear that the craftsman must soon disappear from the industrial scene. Such, of course, is not the case. The more automatic and the more complex production machines become, the greater is the need for expert workers—not to operate the machines, but to turn out the tools and fixtures that make the equipment capable of producing accurate work.

Unlike the conventional drill jigs of only a few short years ago, in which bushing holes were positioned to within a thousandth, or at best a half thousandth, the new equipment demands accuracy to hundredths of thousandths, even to millionths.

To meet these demands, The Moore Special Tool Company developed its first jig borer in 1931, followed it in 1940 by the first jig grinder, and has pursued a constant program of improvement up to the present time. With these precision tools, it became possible for the toolmaker to meet the increasing demands for closer and closer accuracy. The machines were there, but where were the men to operate them? Jig boring and jig grinding called for a new skill to be learned by the toolmaker—and there were no textbooks available. Learning by doing was possible, but could prove costly in terms of spoiled work and wasted time. Yet it was not feasible to send all operators to special training schools, nor to have a factory-trained instructor spend weeks in every customer's plant.

Moore solved the problem—transferring its own skill to its machines through the medium of a book, "Precision Hole Location," published in 1946.

Now, in this new book, "Holes, Contours and Surfaces," Moore passes along another important volume of information gathered from its own thirty years of experience in the field. It deals with hole location, too, but goes much farther and considers the grinding of contours and surfaces and the newly developed technique of linear form grinding, as performed on a new machine just introduced by the company.

Like its predecessor, this book is outstanding for its clarity of expression, its technical accuracy, its excellent illustrations, and the remarkable craftsmanship of its two authors, Richard F. Moore, president of the company, and Frederick C. Victory, chief engineer. To an extraordinary degree, they have succeeded in putting their own knowledge onto the

printed page, and doing this in a manner that permits the reader to acquire that same knowledge for himself with a minimum of time and effort.

It is, first of all, a technical book, but it is eminently readable and, from the standpoint of one who has spent his life in the publishing business, an excellent example of the highest quality of typography and book publishing. For this, Fred Wittner (Fred Wittner Advertising) deserves praise for his work in organization and presentation. It is not a book for the Ivory Tower scholar; it is a working man's book; a book for the tool engineer, the process engineer, the toolmaker, and the jig borer and grinder operator. It fills an urgent need and should live long on the bookshelves and work benches of the American Metalworking Industry.

BURNHAM FINNEY

*Editor, American Machinist*

*New York City, December 15, 1954*

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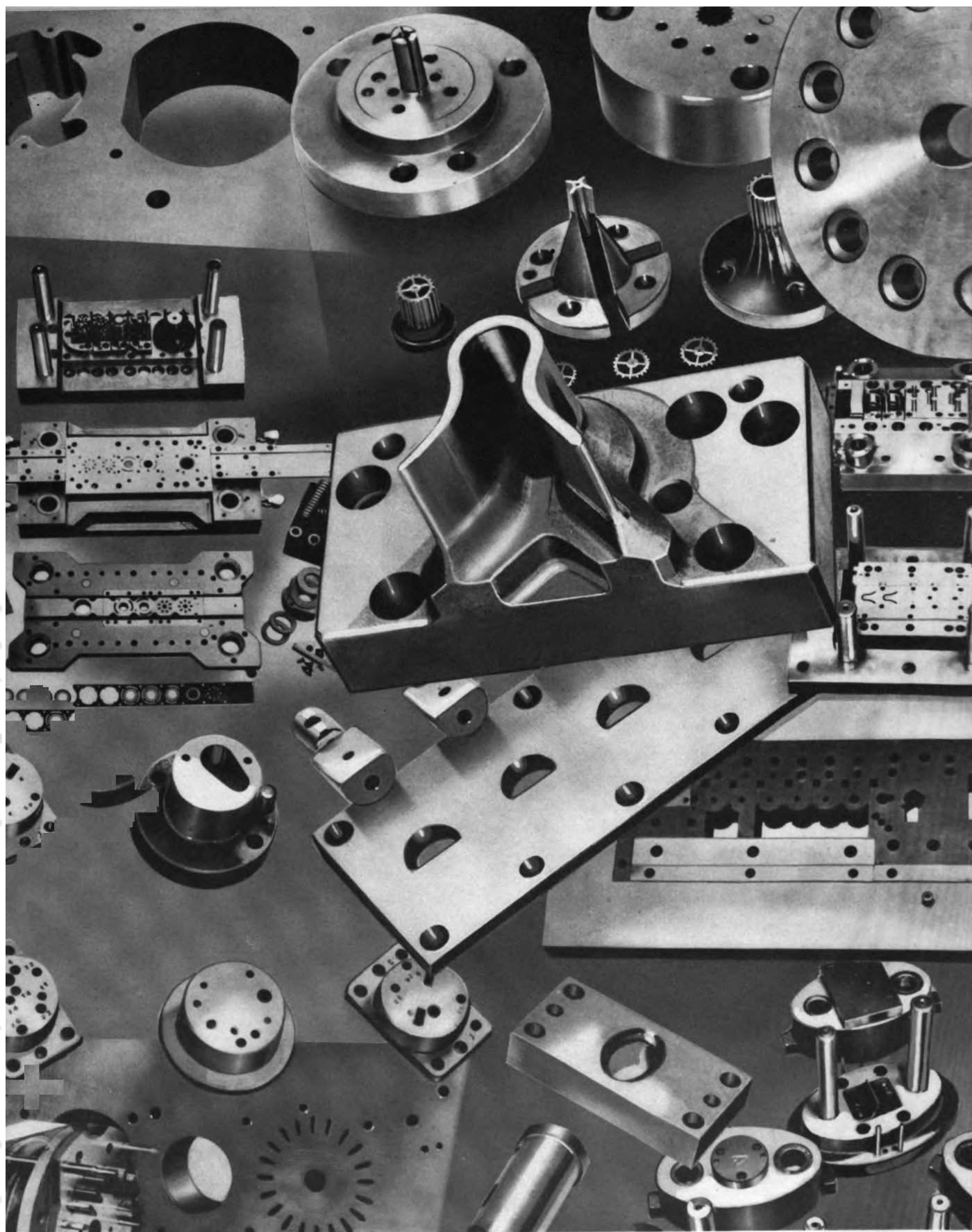
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*The Problem of Location.*



## THE PROBLEM OF LOCATION

OUR mechanized civilization owes a great debt to the toolmaker. His skill and ingenuity have, in large measure, made possible the vast production which provides the United States with the highest standard of living the world has ever known. Yet it is an ironic fact that the toolmaker, in his own work, has never fully benefited from the use of accurate, interchangeable parts, the very essence of the system to which he has contributed so much.

Tremendous effort has been expended in making efficient tools, but relatively little to provide the facilities for making tools efficiently. Rather than say "Physician, heal thyself," it is the purpose of this book to discuss methods and equipment which provide *engineered* solutions to the toolmaker's most serious problem: the accurate location of holes, contours and surfaces.

It may appear at first glance that this problem of location is merely a matter of measurement. Actually, there is a big difference between the ability to measure accurately the location of existing holes, contours and surfaces, and the actual job of generating them precisely in a desired location and to a predetermined size. The science of measurement — metrology — concerns itself with a comparison of some dimension with an accepted standard, a comparison based entirely on static, or fixed, values. In contrast, the actual machining of holes, contours or surfaces involves dynamic, ever-changing values, yet has as its goal the same order of accuracy expected of simple

measurement. These changing values — i.e., stock removal, stresses, deflection, temperature changes and distortion — represent the basic difference between location and measurement.

Accuracy, as a term, must necessarily imply degree. Absolute accuracy exists only in theory. Progress toward this unattainable goal can be compared to that of the frog which, starting from the middle of a table, covered half the distance from his last position to the edge with each jump, and could thus never quite reach the edge. In strides toward greater locational accuracy, the earliest gains were most impressive because there was so much room for improvement. Now, progress is slower, the gains proportionally smaller and the problems increasingly perplexing.

No wonder it is taxing for the toolmaker to work as accurately to location as the inspector can measure! The technology of precise location presents problems of metrology, physics, geometry and metallurgy. In many cases these problems are so involved that they must pass unrecognized by the average craftsman; it is certainly beyond reasonable expectation that the toolmaker, as an individual, should cope with them.

It is no longer a question of further refinement of the time-honored toolmaker locating methods of buttoning, layout or transfer. The time has come for the acceptance of a new concept of location, based on specialized equipment and methods. Such equipment,

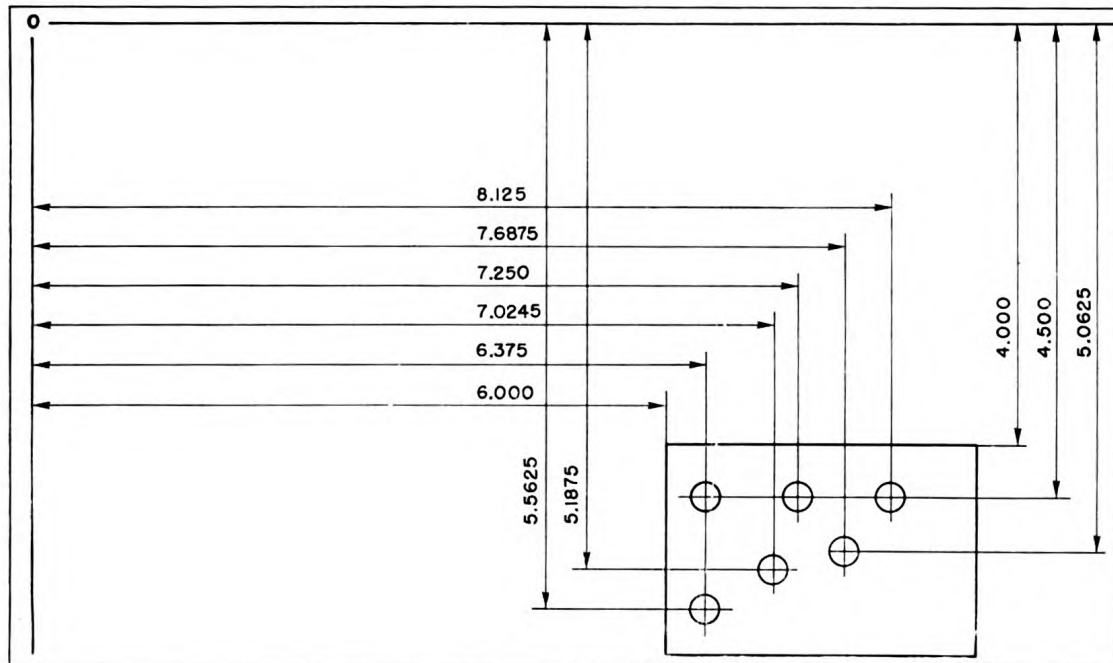


Fig. 1 — Coordinate dimension lines continued to zero lines.

although not yet commonplace, has amply proven its ability to generate holes, contours and surfaces with a locational accuracy and dimensional control well within the existing needs of today and the predictable demands of tomorrow.

Since no equipment is entirely unaffected by the human element or the physical conditions under which it operates, a brief discussion of the general philosophy of locational accuracy in recognition of these points should precede detailed consideration of the equipment itself.

The first requirement in location of holes or radii is the choice of a suitable method — in design — for specifying location dimensionally. This should be done in a form which can be used directly in positioning the work for machining. The axis of any hole or radius is a point in a plane perpendicular to that axis, and the location of any point in a plane can be established by rectangular coordinates. Therefore, the rectangular coordinate system of dimensioning is called the common denominator of location. A typical example, Fig. 1, illustrates how all locations can be

dimensioned from arbitrary datum or zero lines bracketing the workpiece at 90°.

Further advantages of this system will be

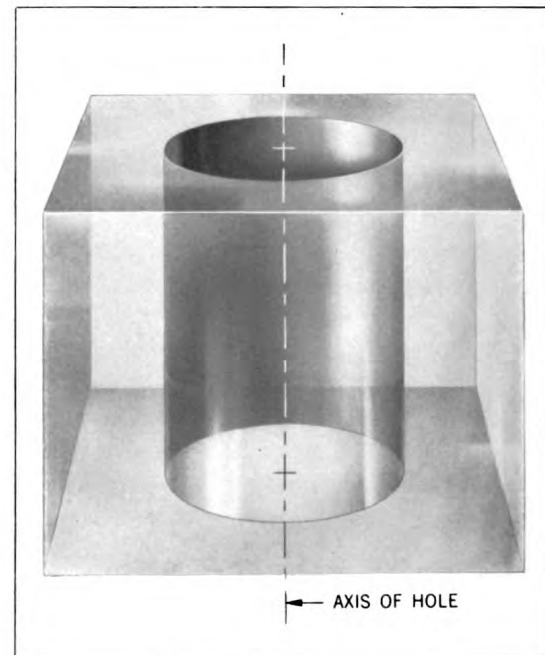


Fig. 2 — Alignment of axis and geometry of form are part of the problem of hole location.

## THE PROBLEM OF LOCATION

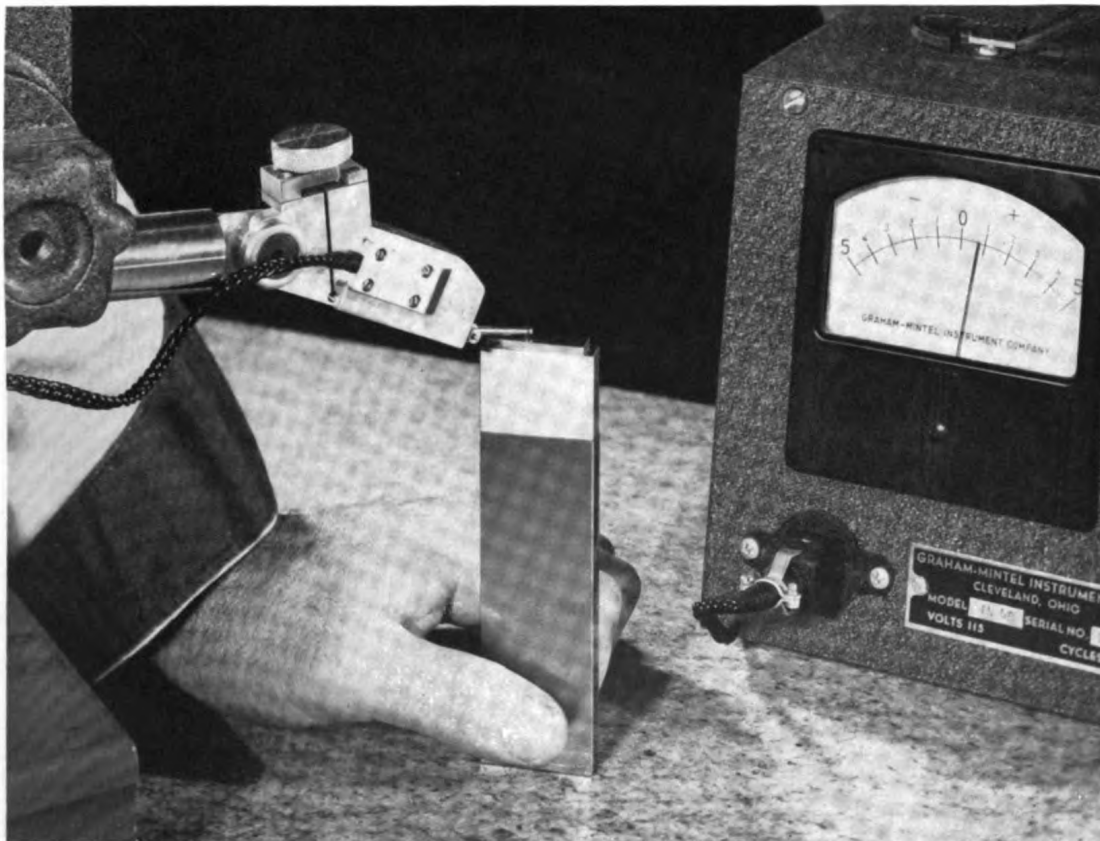
discussed, as related to equipment, in Chapters 4 and 6.

Holes, radii and surfaces must be defined by more than the two dimensions required to position them in relation to a plane. Problems of solid as well as plane geometry arise, Fig. 2. It is not sufficient merely to start a hole accurately in position on a surface. This accuracy must be projected the full length of the hole. Not only must the axis of the hole be correct, but so must its form, whether cylindrical, conical or whatever the requirements.

The physical law of thermal expansion plays an important role in locational accuracy. Different materials such as steel, aluminum and carbide expand and contract at

different rates when subjected to temperature changes. This applies not only to a workpiece, but also to any physical standard of measurement such as gages, Fig. 3, scales or micrometer screws. So important is this consideration that all precise measurements are stipulated to be made at standard temperature ( $68^{\circ}\text{F.}$ ), a condition not often attainable under actual machining conditions. Failure to recognize and make allowances for this factor will greatly reduce accuracy.

Attaining a high degree of accuracy is not, in itself, necessarily a satisfactory achievement, if this accuracy is only temporary. Should the work have been done on a piece subjected to wear, accuracy will diminish with use. On the other hand, if the workpiece



*Fig. 3 — An appreciable period of time is required for gages to reach a temperature equilibrium after being handled. This can be demonstrated by momentarily holding a gage block mounted under a sensitive comparator and watching the pointer climb. It will be observed that it takes considerably longer to drop back again.*



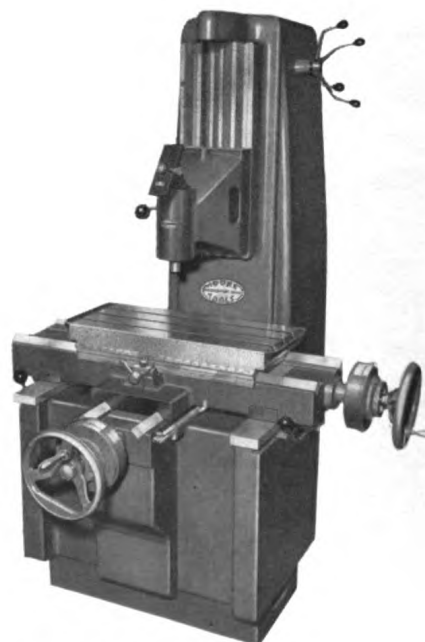
*Jig Borer*



*Jig Grinder*



*Form Grinding Machine*



*Universal Measuring Machine*

*Fig. 4 — Companions in locational accuracy.*

## THE PROBLEM OF LOCATION

is of hardened steel to resist wear, a new set of difficulties arises. These can be classed under the rather formidable heading of "Dimensional Instability."

Dimensional change appears in either temporary or permanent forms. Temporary dimensional change results from the effect of some influence *outside* the piece, upon the removal of which accuracy is restored. Two typical examples are thermal expansion, previously mentioned, and deflection by pressure or force. These temporary forms of instability occur impartially in hard or soft material.

Permanent instability occurs only in hardened steel as a result of a change in the molecular structure of the steel after hardening. This form of instability, because it is not widely

understood or easily identified, is particularly troublesome. It may appear either as growth or shrinkage in an easily measurable amount, within a few weeks of hardening, or in hardly detectable changes over a period of months. Sometimes a balance of forces within the structure will allow it to remain apparently stable until some external condition, such as a sudden temperature change or physical shock, triggers the molecular change, resulting in a dramatic and apparently inexplicable dimensional change in the steel.

Overcoming such problems involves money and effort. In order to justify this investment it is reasonable to expect some dividends; therefore, it may be briefly stated that "precision both costs and pays."

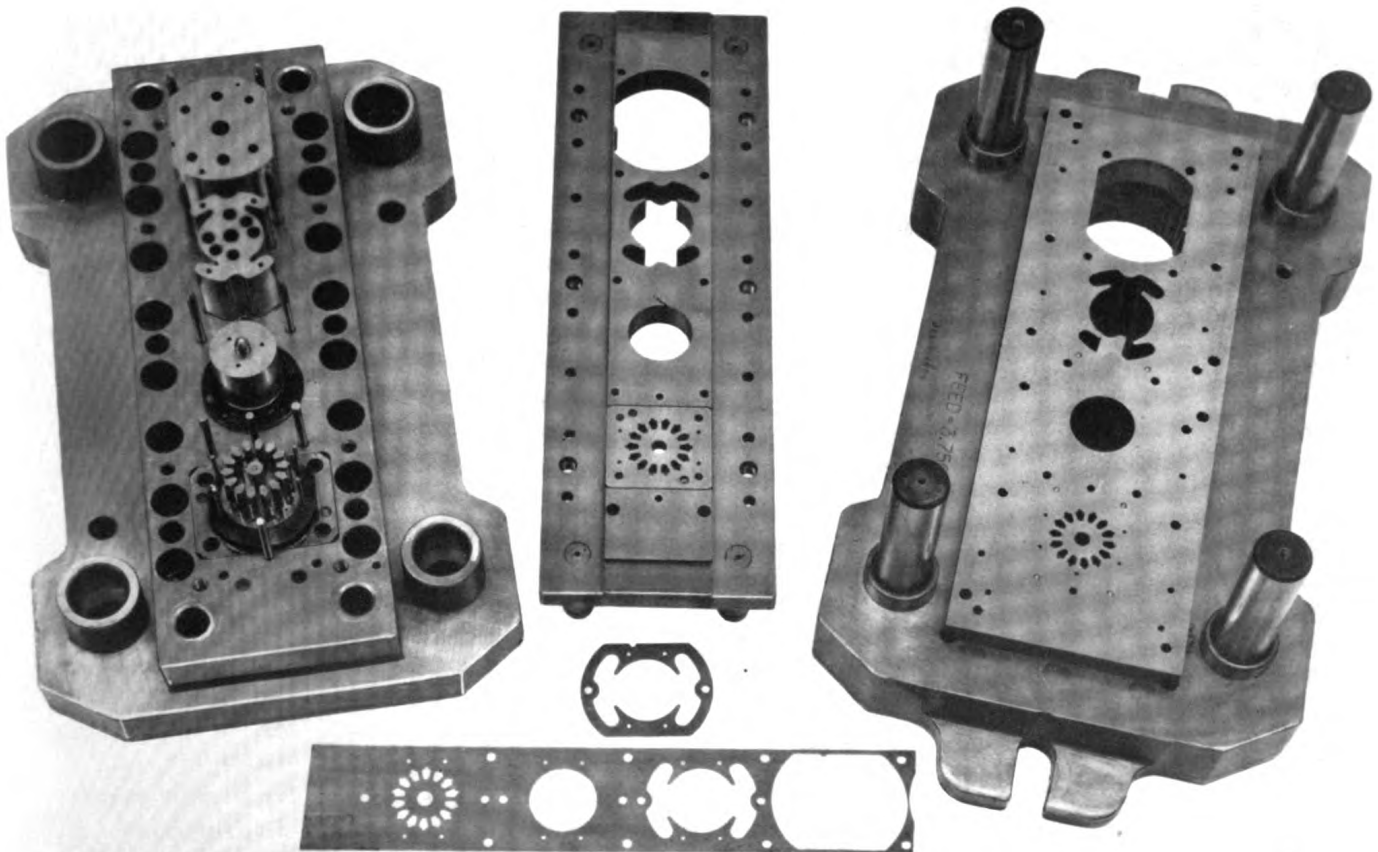


Fig. 5 — Stator-rotor lamination die, to be used repeatedly as an example.

To evaluate the economic aspects of higher locational accuracy, the possible advantages must be convincingly demonstrated. This is possible in most cases. Typical considerations may include:

1. More rapid and economical production of tools through interchangeable parts *made to figures* and not just to fit.
2. Better quality tools capable of producing more accurate and cheaper products.
3. Cheaper and more accurate experimental, model work.
4. Tool-less production of pilot-run lots of products requiring locational accuracy.

Greatly weighing the balance in favor of higher accuracy is the availability of specialized equipment such as the modern Jig Borer, Jig Grinder, Form Grinding Machine and Measuring Machine, Fig. 4. Use of these engineered solutions to locational problems reduces the price of precision. So significant has been the effect of their introduction to the toolmaking industry that *those who use them enjoy a strong competitive advantage over users of the buttoning, layout and transfer methods of location.*

The introduction of new equipment requires new methods in order to realize the fullest gains. Ingenious though the machine designer may be, he has not yet found a mechanical substitute for common sense.

Repeated reference has been made to the toolmaker's location problems, because his is the primary need for accuracy of location. Once established in the tool, this accuracy is reproduced in the final product. He has had few aids in contending with this problem, the wide variety and non-repetitive nature of his work precluding his own use of jigs and fixtures, the conventional locating tools used by production workers.

Having started as a contract tool and die shop, it was logical for The Moore Special Tool Company to be keenly aware of these problems. In 1930, it undertook the development of a Jig Borer especially designed for rapid, accurate toolroom use. The need for

a machine to serve the same purpose in hardened material led to the development of the Jig Grinder by Moore about ten years later. Today the Jig Grinder grinds enclosed contours as well as straight or tapered holes. A Form Grinder, which combines diamond-dressing and roll-crushing of wheels with surface grinding in one compact machine, was recently added to this array of related toolroom equipment. The Moore Measuring Machine, Fig. 4, was introduced to provide the ultimate in precision and efficiency in verifying the accuracy of work produced on the Jig Borer, Jig Grinder and Form Grinding Machine. It also measures many unrelated types of work.

These machines have made it possible for the toolmaker to allocate his time more effectively to other phases of the job. Location of holes, contours and surfaces becomes the function of machine operators.

Analysis of the principles, equipment and operating practices in the precise location of holes, contours and surfaces, in answer to the problems posed in this chapter, will form the subject matter for the remainder of this book.

A representative selection of workpieces will illustrate the principles and practices to be discussed in the following chapters. However, the desirability of an all-inclusive "classic example" led to the choice of a high production, progressive lamination die, Fig. 5. In this role it conforms to all of the requirements, including:

1. It is a practical product of engineered locating equipment and methods.
2. It incorporates virtually the ultimate requirement of each phase of precise location of holes, contours and surfaces.
3. Its products, stator and rotor laminations, are so common that it represents a universally recognizable problem in diemaking.
4. While each of its stations and component parts provides a suitable example for illustration of a locating method, the interdependence of these locations establishes a continuity of illustration.

## THE PROBLEM OF LOCATION

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*Improved Location Equipment and Methods.*



## IMPROVISED LOCATION EQUIPMENT AND METHODS

LOCATION has plagued the toolmaker since the beginning of our mechanical era. Until the fairly recent development of engineered location equipment and methods (Chapter 4), he was entirely dependent upon his own skill in using such toolroom machines and measuring instruments as he had available. Before examining and evaluating the engineered methods, let's examine what the toolmaker did — and in many cases is still doing — without them. It will help us to understand the significance of the toolroom evolution that is well under way.

Let's first take a look at what the toolmaker, left to his own devices, has done about location. This will reveal the tedious and inefficient methods, though reasonably accurate, which he developed for himself. Then we will take up the economic reasons behind the present evolution and displacement of improvised methods.

Each problem of location can be broken down into three basic operations:

1. **Locating**, or establishing the desired position of the finished hole in the workpiece.
2. **Machining**, or removal of material to produce a hole of the desired size and as nearly as possible in the position determined by the locating method employed.
3. **Inspection**, or checking location of the finished hole to determine whether it is within acceptable limits, or whether correction is necessary.

Each of these separate operations may be accomplished with varying results by a variety

of methods. Since certain locating techniques are more adaptable to some machining methods than others, and vice versa, a suitable combination is determined by the nature of the job. Under these conditions, the toolmaker has no effective shortcut to accuracy.

The potential accuracy of each operation is lessened by the number of steps involved. It is still further reduced by the transition error introduced between each of the three basic operations. This transition error results from the fact that the workpiece must be moved and re-located for each operation, and it is impossible to predict the magnitude of the final error. Whenever the human element varies, as it does here, these methods must be considered inconsistent at best.

*Locating*, the first operation, is commonly accomplished by one of three methods, i.e., layout, buttoning or transfer; each of which, in turn, permits a choice of techniques, as follows:

**A. Layout**, or scribing of lines on the workpiece, which, by their intersection, indicate the desired position of the finished hole. Emphasis by a prick-punch mark is necessary to provide an adequate mark by which this intersection can be aligned with the axis of the cutting tool. This additional step further reduces scribing accuracy.

1. A combination square and hand scribe is the quickest but least accurate of the layout methods. The coarseness of scale graduations, necessity of reading against the edge of the square

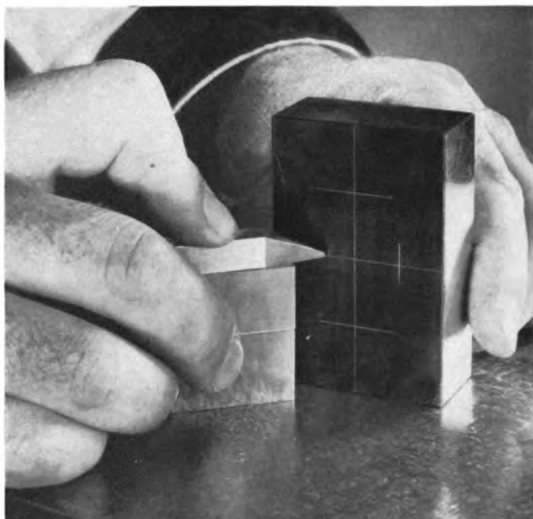


Fig. 6 — Use of a special, lapped scriber and gage blocks for layout.

and the uncertain angle of the scriber all limit accuracy.

2. Use of a surface gage permits somewhat higher accuracy, since it eliminates errors resulting from reading graduations against an obscuring edge and variable scriber angle.
3. A height gage is more accurate and convenient than either of the previous methods.
4. Slightly less handy but more accurate is a planer gage, set to a micrometer caliper.
5. The highest accuracy possible with the layout method results from use of gage blocks and a special, lapped scriber, Fig. 6. Even so, location of the final prick-punch mark cannot be expected to be closer than  $\pm .0003"$ , and may represent a significantly greater error.

**B. Buttoning**, or establishing the desired location of the finished hole in the workpiece by means of a cylindrical toolmaker's button. With a soft workpiece, the button is attached to the face of the work by screw in a hole tapped in approximately the desired position. Where a hole is to be re-located in a hardened piece, the button is fastened through the existing hole. In either case, the screw is loose enough in the button to permit movement, so that the latter can be moved to desired position and the screw tightened. This positioning is a painstaking and tedious operation, because the button must be aligned in two directions.

A tap in one direction almost invariably displaces it in the other direction. Final tightening of the screw often shifts the button, making it necessary to re-check and re-locate.

1. A height gage is sometimes used as a means of establishing the location of the button. It provides somewhat higher accuracy than when used for laying out, since the prick-punch error is eliminated.
2. Gage blocks, together with an indicator, make it possible to locate a button within  $\pm .0001"$ , Fig. 7.

**C. Transfer**, or establishing the desired position of the finished hole in the workpiece by relating it to a corresponding hole in a matching piece. This method is most often used where alignment of holes in two pieces is more important than their location to dimensions. Frequently, the exact location of the original hole is not known or need not be determined.

1. Special prick-punches guided by the hole in the existing piece may be used to mark the desired location on the workpiece.
2. The original piece may be used as a guide or jig when drilling the workpiece.
3. Indicating the hole in the master, which is clamped to the workpiece prior to boring, is the most accurate of the transfer techniques. This permits accuracy approximately equal to that attainable by buttoning.

Fig. 7 — Locating button on die block. This is an extremely painstaking operation since the button must be aligned in two directions.



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The time-honored saying, "There is many a slip between the cup and the lip," must often occur to the exasperated toolmaker as he labors by one of the methods outlined to place the hole exactly in the position he has painstakingly established. No matter how carefully he works, there is almost certain to be an additional inaccuracy of pickup introduced at this stage, Fig. 8. This is the transition error. It is separate and distinct from the errors of location and those likely to occur later during machining.

This transition error is introduced regardless of the locating and machining methods employed, but will vary in magnitude as a result of the combination chosen.

In working from a layout, should a drill press be used, the drill must be initially guided by the prick-punch mark. This limits accuracy. Locating the mark in alignment with the spindle axis for single-point boring is only slightly more accurate, even when a "wiggler" or pump center is used as a pickup. Buttons must be also related to the spindle axis for boring or grinding by indicating, a step never free of error. The remaining locating method,

transfer, also introduces one of the two forms of transition error in setting up for machining, regardless of whether the hole is drilled, bored or ground.

*Machining*, the second operation, can be limited to the three basic methods which actually influence the accuracy of location, i.e., drilling, single-point boring or grinding. Naturally, the type and condition of the machine used will also affect the resulting locational accuracy. Commonly used methods are outlined as follows:

**A. Drilling**, as a method of establishing the location of a hole in machining, is the least accurate of the available methods. This is due to the unpredictable influence of improperly ground drills and the fact that they are always guided to some extent by the material being drilled.

1. Drilling directly from a layout involves opening up the hole to size by the use of progressively larger drills, each one reducing, by some amount, the degree of accuracy of pickup.
2. The use of a drill guide such as a bushing or master hole in a matching piece is only slightly more accurate, since a running clearance must exist between guide and drill.



Fig. 8 — Picking up the location of a prick-punch mark with pump center and indicator, representing the introduction of the transition error.



Fig. 9 — Single-point boring in a lathe, as a means of establishing location, represents the correct principle in the wrong machine.

**B. Single-Point Boring** is capable of producing the highest degree of locational accuracy in machining a hole in soft material. This is possible because the axis of the hole is generated from the axis of the machine spindle, a geometrically sound principle. In practice, this accuracy is subject to reduction by several factors:

1. In toolmaker methods of location, at least, most boring is done in a lathe, Fig. 9. Seldom is the spindle good enough to insure running true to the "tenth." Any looseness in the bearings will cause inconsistent indicator readings during initial pickup and will also bore out of location. If the piece is unsymmetrical, as is usually the case, even careful counterbalancing will not entirely eliminate all displacement while boring. Clamping the workpiece tightly enough to resist both centrifugal force and the thrust of the tool will often distort it, with a probable loss of accuracy.
2. Even the use of a machine such as a vertical miller, permitting the work to remain stationary as the tool rotates, seldom improves conditions, since the spindle would be unlikely to offer much better conditions than found in a lathe. Countering the advantage of having the workpiece fixed, the construction of most vertical spindle machines is such that its geometry, i.e., squareness of spindle to table, would be questionable.



Fig. 10 — The potential locational accuracy attainable by grinding cannot be developed under makeshift conditions.

**C. Grinding**, the equivalent of boring when it is necessary to re-locate a hole in a hardened piece, is capable of the same high order of accuracy, but is subject to the same reduction of accuracy in practice, due to unsuitable equipment and operating conditions, Fig. 10.

Having finally established the position of the machined hole, it is necessary to determine how close it actually is to the desired location. At this point, a second transition error is introduced, as the work must be set up and the hole checked under different conditions and by different methods from those by which it was either located or machined.

*Inspection* or checking, the third operation, is always time-consuming. Even when the error is measured, an element of doubt as to the truth of the findings remains; also whether an attempt at correction would result in real improvement.

Location of the finished hole is checked by measurement directly to the edge of the hole itself, or to a projecting plug tightly fitted to the hole. Several methods are commonly used for this operation:

**A. Vernier Calipers** may be used to check the distance between any two holes. This method, however, does not take angular displacement into account. Similarly, plugs projecting from holes permit the use of micrometer calipers in the same manner.

**B. An Indicator** permits direct comparison between the surface of the hole and gage blocks, working from finished edges of the workpiece standing on a surface plate.

**C. A Height Gage** is sometimes substituted for blocks. In any event, results of this and the preceding methods are dependent to a large extent on the squareness of the edges to each other and to the face of the workpiece, and the accuracy of the reference plane (surface plate).

Contours and surfaces involve even greater location problems than does the simpler geometric form of the hole. The mere variety of contours gives an indication of the complexity of this aspect of the problem: External and internal, composed of curves, male and



*Fig. 11 — Filing and fitting to a template would be a tedious and exacting operation for a contour like that of the stator-rotor lamination die.*

female radii, acute and obtuse angles in every conceivable combination. Here again, the toolmaker, left to draw largely on his own skill and ingenuity, has tried many ways to solve these problems, none entirely satisfactory.

A. Machining, or filing to a layout or template, one of the "rough and ready" methods, Fig. 11, is seldom good enough

where real accuracy is required. However, in many cases this is the only practical method available.

B. Where size permits, higher accuracy can be achieved by comparing the work with an enlarged layout in a magnifying projector.

C. Some few forms lend themselves to machining by turning or milling with formed tools.

D. Soft punches may be sheared into a hard die, providing a mark which then serves as a guide for machining and filing.

E. After hardening, matching pieces such as punches and dies can be stoned to fit each other. Neither is then accurate to dimensions.

F. Certain forms can be ground after hardening, using wheels dressed to simple radii and/or angles. The chief drawback to this method is the wheel truing problem, which requires high skill with the inadequate equipment usually available.

It was inevitable the inefficiency, unreliability and dependence upon individual skill of these toolmaker methods of locating holes and contours should eventually bring about the development of mechanical aids *engineered* to solve locating problems. While the ultimate in these developments are the Jig Borer, the Jig Grinder and the Form Grinding Machine, other interim solutions are worthy of note. The latter, in most instances, fall halfway between toolmaker methods on the one hand and special-purpose machines on the other, both in accuracy and efficiency.

Numerous attempts have been made, for example, to convert vertical-spindle milling machines into Jig Borers. Superficially, it would appear that the addition of a measuring system would serve this purpose. However, several factors preclude the attainment by a milling machine of accuracy comparable to that of a Jig Borer, even with an identical measuring system. A milling machine — with its gibbed, vertically adjustable knee, slide and table — lacks rigidity. Besides, the general construction, spindle design and alignment of positioning elements are not sufficiently good to transfer all of the accuracy of the measuring system to the work.

Conversion of a vertical-spindle milling machine to serve as a Jig Grinder involves even greater difficulty. A high-speed grinding spindle must be mounted eccentrically on the main spindle, plus the same need for a measuring system. Together, these two additions provide an approximation of the basic rectilinear positioning movement and planetary grinding

movement required for Jig Grinding. Due to the relatively greater complexity and refinement necessary in a true Jig Grinder, this type of conversion is less satisfactory than that to a Jig Borer.

Form Grinding Machines are frequently improvised from conventional surface grinders by the addition of one of a variety of wheel-contouring devices, including crusher roll systems. The basic unsuitability of design and construction encountered in any conversion limits accuracy and efficiency.

Two factors are common to all of these examples of improvised equipment. The first and obvious one is the almost universal acknowledgment that a need exists for specialized locating equipment. Besides, superficial similarity of general design and basic movement is no insurance of accurate duplication of performance. On the contrary, this can prove to be a dangerous pitfall.

Yet improvised equipment has a value far beyond its mere productivity. It serves to introduce the logic of special-purpose locating equipment and to demonstrate what can be accomplished by following this reasoning to its conclusion.

Thus far, we have considered the toolmaker as an individual. His problems of precise location, greatly multiplied, bring about an impact on the entire toolmaking industry that is difficult to calculate. The toolmaker sees it largely as a technical obstacle to be overcome in his daily work. Supervision and management, however, having a greater perspective, know its effect on cost, quality, interchangeability and delivery of tools.

Not only does industry exert strong pressure toward higher quality tools for greater production, but it also demands more complete interchangeability, particularly in power press tools. These tools, an integral part of many production lines, must be capable of rapid repair or replacement. This is impossible unless all parts of the tool can be exactly duplicated, not merely made to fit mating parts. For example, where delicate punches are involved, it is not uncommon for the

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supplier to provide the customer with replacements on short notice. These must be capable of assembly into the tool without stoning or fitting.

The industrial tempo of rapidly changing product design also exerts a strong pressure toward shortening the delivery period for tools. No longer is it reasonable to expect customers to wait several months for the delivery of even the most complex, multi-station press tools. Yet where the location of holes, contours and surfaces is entirely dependent on toolmaker methods, there is no alternative. Work must progress according to the old-fashioned system of finishing one part at a time, *one after the other*. Providing him with helpers is of little account. He must carry the work through to completion, largely through his own efforts. His productivity is limited by the tedious nature of his locating methods. Where many hundreds of man-hours are represented in a tool, it is readily apparent that delivery must necessarily be a long-range proposition.

Shortcuts, resulting from the pressure for early delivery, together with the variable

human element and basic limitation of accuracy in toolmaker locating methods, all tend to compromise quality. This is reflected both in tool life and accuracy of work. Time-consuming toolmaker locating methods also make any appreciable reduction in cost virtually impossible, except at the sacrifice of quality.

If all toolmaking were subject to these limitations, the problem would be serious enough. However, the more progressive toolmaking firms and manufacturers have adopted the principles of *engineered* locating equipment as a solution, with a resulting advantage in delivery, accuracy, quality, interchangeability and cost. Those who haven't followed suit are at a serious competitive disadvantage.

While it seems inevitable that this solution will ultimately be universally adopted, there are many who are not fully aware of the principles of precision location as exemplified in the Jig Borer, Jig Grinder, Form Grinder and Measuring Machine. The chapters to follow are devoted to their philosophy of design, construction and operation — as well as the results to be expected from their use.



*The Foundation of Accuracy.*

## CHAPTER 3

### THE FOUNDATION OF ACCURACY

REFERENCE in the previous chapter to the inaccuracies common to toolmaker methods of establishing location is in no sense intended as destructive criticism. It does point up the conditions which render the attainment of high accuracy both tedious and difficult to achieve.

Before discussing the *engineered* solutions — namely, those machines designed specifically for the purpose — it is appropriate to consider the origin of the accuracy built into them. This material will provide a background for those desiring to familiarize themselves with the fundamentals of precise measurement of length, angle and form, upon which is based the precise location of holes, contours and surfaces. This is the science of engineering metrology. Relating the machine's accuracy to the work requirements will also be described.

The foundation of accuracy is the flat plane, a true perpendicular to it, and a standard of linear measurement. These fundamental requisites of precision are maintained at the Moore inspection laboratory in the following forms:

1. The flat plane is represented by a master surface plate, Fig. 12. This plate, or planes developed in the same manner, forms the datum for all geometric and linear relations.
2. A perpendicular to the flat plane is embodied in the true 90° square of both cylindrical and blade design, Fig. 13.
3. Linear standards of measurement include the master screw and a variety of end standards,

Fig. 14, based on the American inch, in increments and multiples.

The flat plane can be developed and verified without recourse to any other standard or master in the following manner:

1. Starting with three surface plates, A, B, and C, Fig. 15, all of unknown flatness, plates A and B are rubbed together and then each is rubbed against the third plate, C. This will develop the bearing of each plate relative to the other two.
2. All three plates are then alternately scraped and tested with each other until a satisfactory bearing is established on each in relation to the other two. *Only true flatness of all three plates will permit this relationship.*

A perpendicular to this plane can be established in the form of a square, and verified in the following manner:

1. Straightness of the sides of the square is first determined by comparison to the flat plate. Parallelism of the sides is insured by indicating along one edge, from the flat plate, Fig. 16.
2. The square is placed on a flat plate, and an indicator is zeroed against the upper end of the square, Fig. 17. The indicator is rigidly supported by a stand which also rests on the plate and contacts the lower end of the square, in a vertical line with the indicator.
3. The square is turned 180° and brought into contact with the indicator and its stand, as in step 2. Any deviation from a true 90° relationship between the square and the plate will be revealed by failure of the indicator to repeat the original zero setting.
4. Deviation from zero represents twice the actual "lean" of the square. This provides a sensitive guide for any necessary correction to the square.



Fig. 12 — The surface plate represents a convenient form of the flat plane.

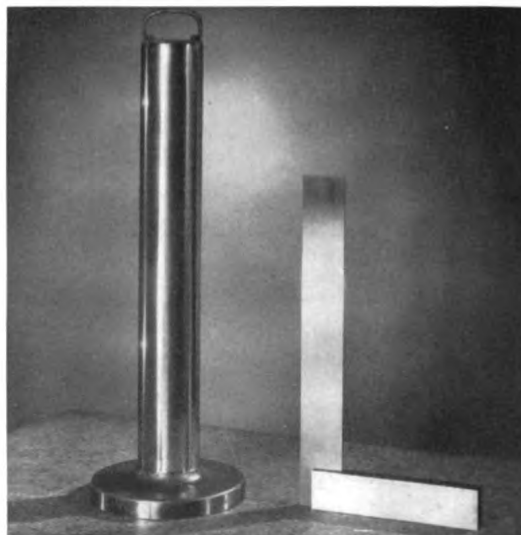
Linear standards are not self-checking. The authority for their accuracy must rest on impartial comparison to nationally maintained primary standards. In the case of Moore linear standards representing the inch, in increments and multiples, this comparison was made both at the National Bureau of Standards in the United States and at the National Physical Laboratory in England. While the institution in Washington is very familiar to American industry, its English counterpart, the N.P.L., is not so well known in the United States.

The Metrology Division of the N.P.L.\* performs the following functions and provides the following facilities for assisting industry:

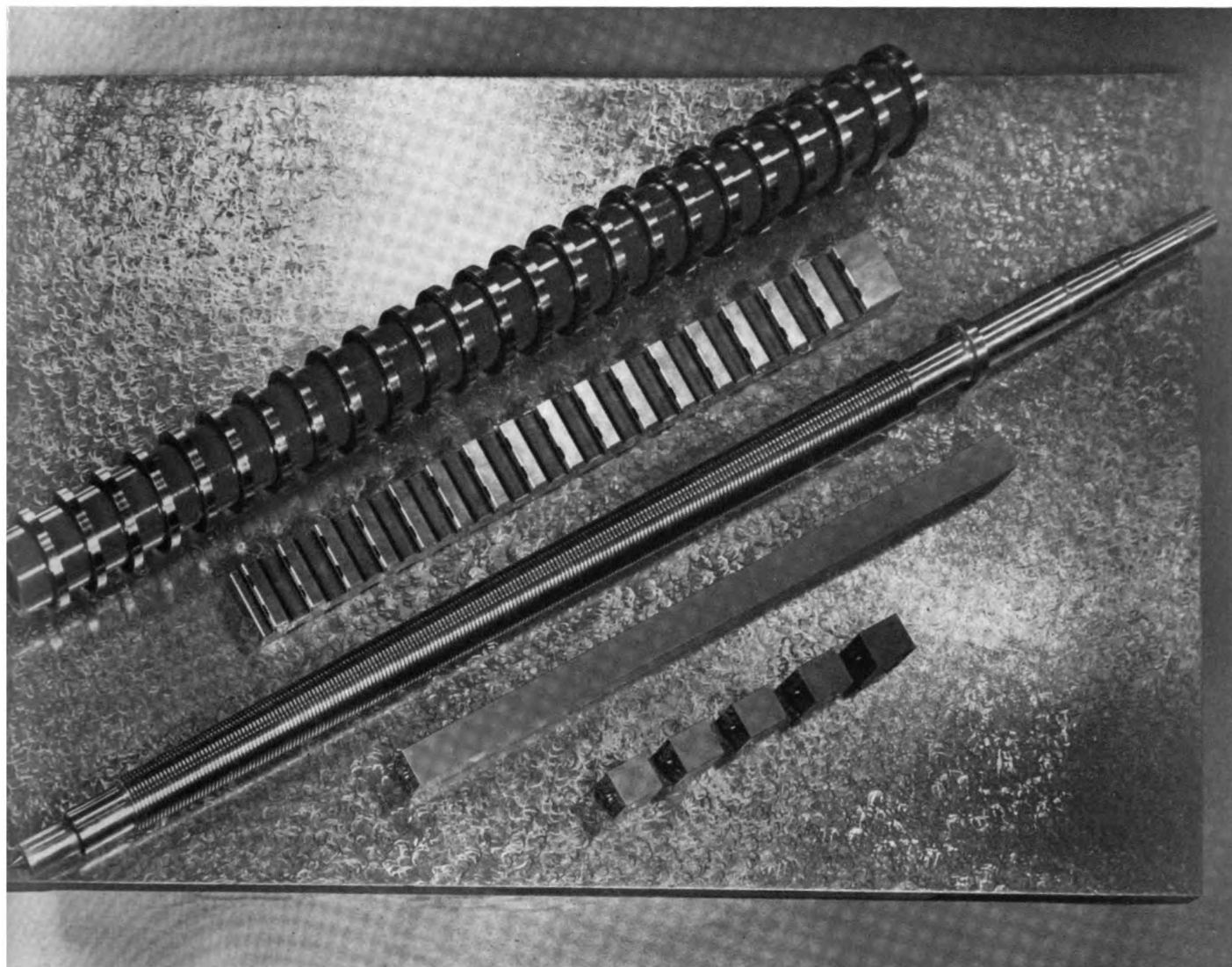
1. Provides and maintains practical standards of length, mass and time, and their more common derivatives, for science and industry.
2. Advises on fundamental matters associated with the definitions of units for these quantities and their simple derivatives; the standard conditions

\* The authors acknowledge the cooperation of the National Physical Laboratory for some of the material appearing in this chapter. See page 53.

Fig. 13 — Both the cylindrical and blade type squares offer advantages in design. The blade square provides a flat surface against which to indicate, and its squareness can be easily corrected, if necessary, by a simple adjustment. The cylindrical square is somewhat more stable where greater height is required, and is not subject to the introduction of angular error from handling.



## THE FOUNDATION OF ACCURACY



*Fig. 14 — The accuracy of linear standards of measurement depends upon initial calibration and periodic verification in relation to some accepted master.*

- of measurement; and the relationships between values of quantities expressed in different systems of units.
3. Investigates and develops methods and apparatus for improving the techniques of measurement of:
    - a) *the three fundamental quantities of length, mass and time;*
    - b) *some of the more direct derivatives, such as volume, density, force and pressure;*
    - c) *angle and shape, particularly for precision engineering purposes.*
  4. Tests for science and industry of certain classes of instruments and equipment used for the purposes of measurement specified above.
  5. Designs and constructs prototype measuring apparatus for these purposes to meet special needs arising in science and industry.
  6. Advises manufacturers of precision measuring equipment on the design and construction of new instruments, including formulation of suitable standards of accuracy and performance to meet the needs of potential users.
- Measurement, then, consists of comparison of some accepted standard to the unknown

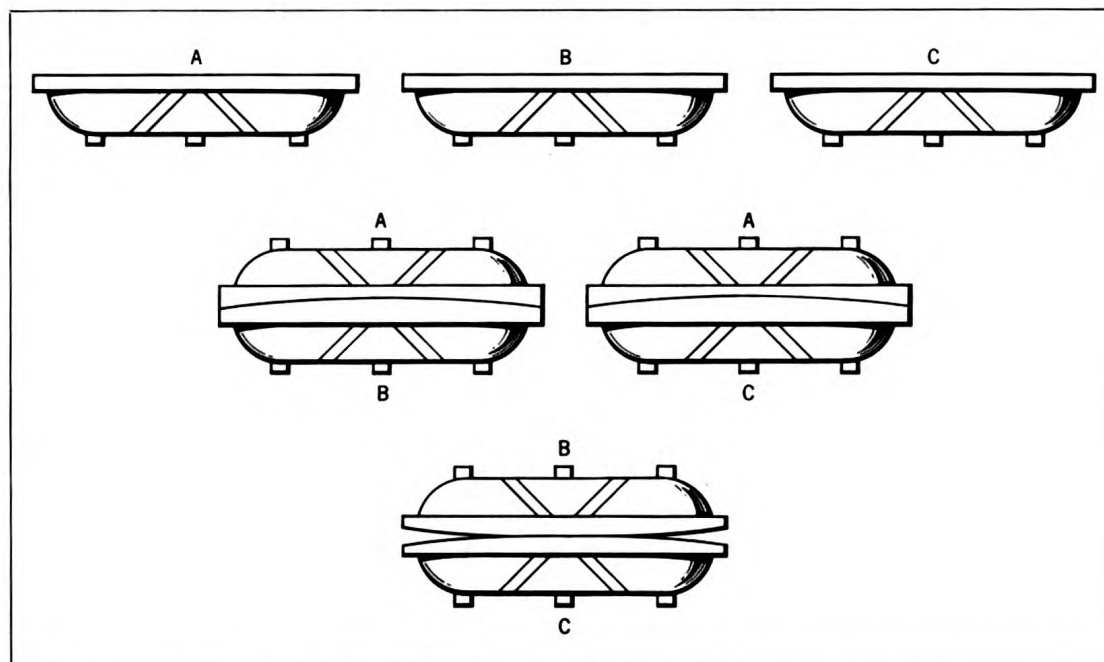


Fig. 15 — Simultaneous generation of three flat planes. If A is concave and B is convex, C will therefore be convex. When C is tested against B, however, the fact that they are both convex is immediately apparent.



Fig. 16 — Having determined the straightness of one edge of a square, the parallelism of the opposite edge is determined by indicating along it from a surface plate.

value represented by the workpiece. The conditions of the comparison — known accuracy of the standard, geometry or relationship of alignment, temperature and means of comparison — all bear an important relationship to the validity of the results. Each, therefore, must be carefully defined in any conclusion as to dimensional accuracy.

Although there are a number of standards, considered by types and sizes, they are necessarily *secondary* standards. They derive authority from direct or indirect comparison with the International Prototype Meter, the basic primary standard of length for the civilized world.

The meter, originally intended to represent a fraction of a certain dimension of the earth, is preserved as a platinum/iridium bar having two fine graduations which define the unit of distance by their separation when the bar is under certain conditions of temperature and support. The graduations give rise to the name "Line Standard."

The United States and the British Commonwealth have adopted national standards in the

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form of the yard. Each is also a line standard and is defined in relation to the meter as follows:

$$\text{United States Standard Yard} \left\{ = \frac{3600}{3937} \text{ of the meter} \right.$$

$$\text{British Imperial Yard} \left\{ = \frac{3600}{3937.0147} \text{ of the meter} \right.$$

Since the inch in both cases is  $1/36$  of the yard, the difference in definition has resulted in the American inch being larger than the British inch by about four millionths of an inch. This difference is just appreciable in relation to the accuracy of gage blocks, slip gages, end measures and lead or micrometer screws, particularly over a distance of several inches.

This relationship is used for scientific and industrial purposes of conversion in which

the highest precision is required, and is based on an experimental determination made in 1922. For purposes of trade, the legal conversion factor of 1898, based on an experimental determination made in 1895, is 1 m. = 39.370113 in. or the British Imperial yard =  $\frac{360}{3937.0113}$  of the meter. Canada, however,

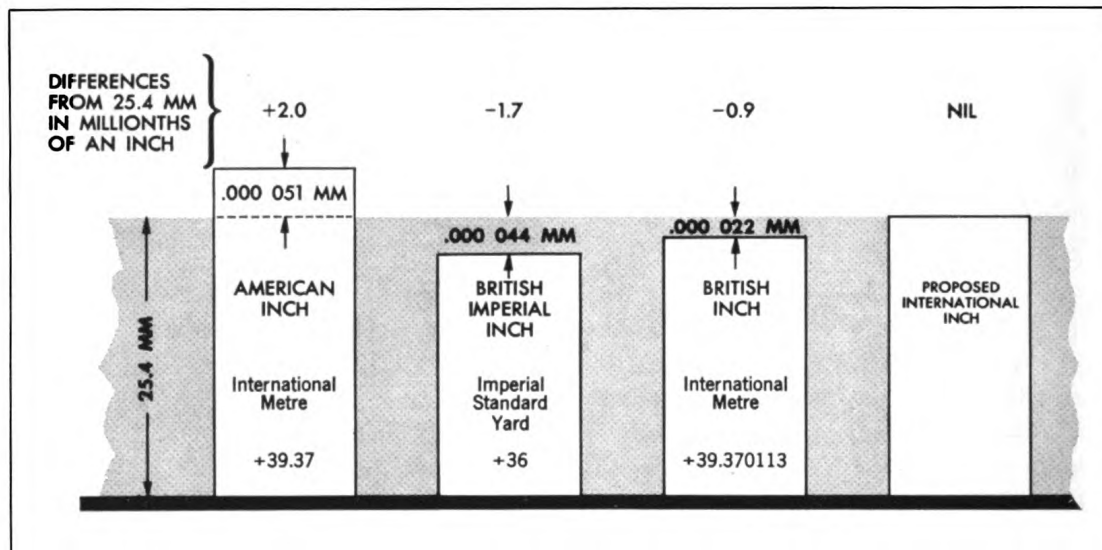
has recently introduced legislation in which the yard is defined as .9144 of the meter, or

$$1 \text{ yard (Canada)} = \frac{3600}{3937.0079} \text{ of the meter;}$$

this latter definition is equivalent to 1 in. = 25.4 mm. exactly. Consideration is now being given to the introduction of legislation in which this simpler relationship (1 yard = .9144 meter) is to be adopted throughout the British Commonwealth as a means of defining the yard in terms of the meter.

Fig. 17 — Checking perpendicularity of a square to a flat plane by use of an indicator.





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Fig. 18 — In spite of unofficial agreements between industrial interests, the official governmental American inch and British inch legally differ by 3.7 millionths.

In view of this discrepancy, it is to be hoped that the proposed official international agreement will result in a compromise value of 1 inch = 25.4 mm. Contrary to misleading statements that have been made, this has not yet been achieved. The relationship of these confusing inches is illustrated in Fig. 18.

The process of developing industrial standards of length has had many ramifications. One of the most interesting is the use of light waves. This technique is now in use commercially and in research. It has been proposed as an alternative and natural standard which may ultimately replace the material definitions of the standards of length now used. Obviously, such a proposal has merit, in view of the fact that any physical standard is subject to physical change, damage or destruction.

The idea of using wave lengths of monochromatic light as a natural and invariable unit of length is more than 125 years old, having been proposed by J. Babinet in 1827. In 1927, international agreement was obtained for the following provisional relationship, based on experimental determinations between the International Prototype Meter and wave lengths of cadmium red light:

$$1 \text{ meter} = 1,553,164.13 \text{ wave lengths.}$$

The reason wave lengths of light have not yet superseded material standards lies in the fact that no natural occurring element, cadmium included, is known to emit waves of light which are entirely free from imperfections. A fortunate by-product of nuclear research has, however, developed an isotope of mercury,  $\text{Hg}^{198}$ , which shows a hundred-fold improvement in the measuring precision of its light waves as compared with natural mercury, and is far superior in this respect to any other natural element. There is no doubt that we shall adopt an ultimate standard of length defined by wave lengths of light. It is equally certain that this will be the wave length of a radiation emitted by a pure isotope such as the artificially produced mercury isotope  $\text{Hg}^{198}$  or the krypton isotope  $\text{Kr}^{84}$  separated from natural krypton.

Great advantages would accrue from the choice of wave lengths of light as a standard. The current problem of subdividing the physical standard into the requisite fractions would be automatically eliminated.

**End Standards** — The length of an end standard is defined as the distance between its flat and parallel terminals, or end faces. The most familiar form of end standard is the gage block,

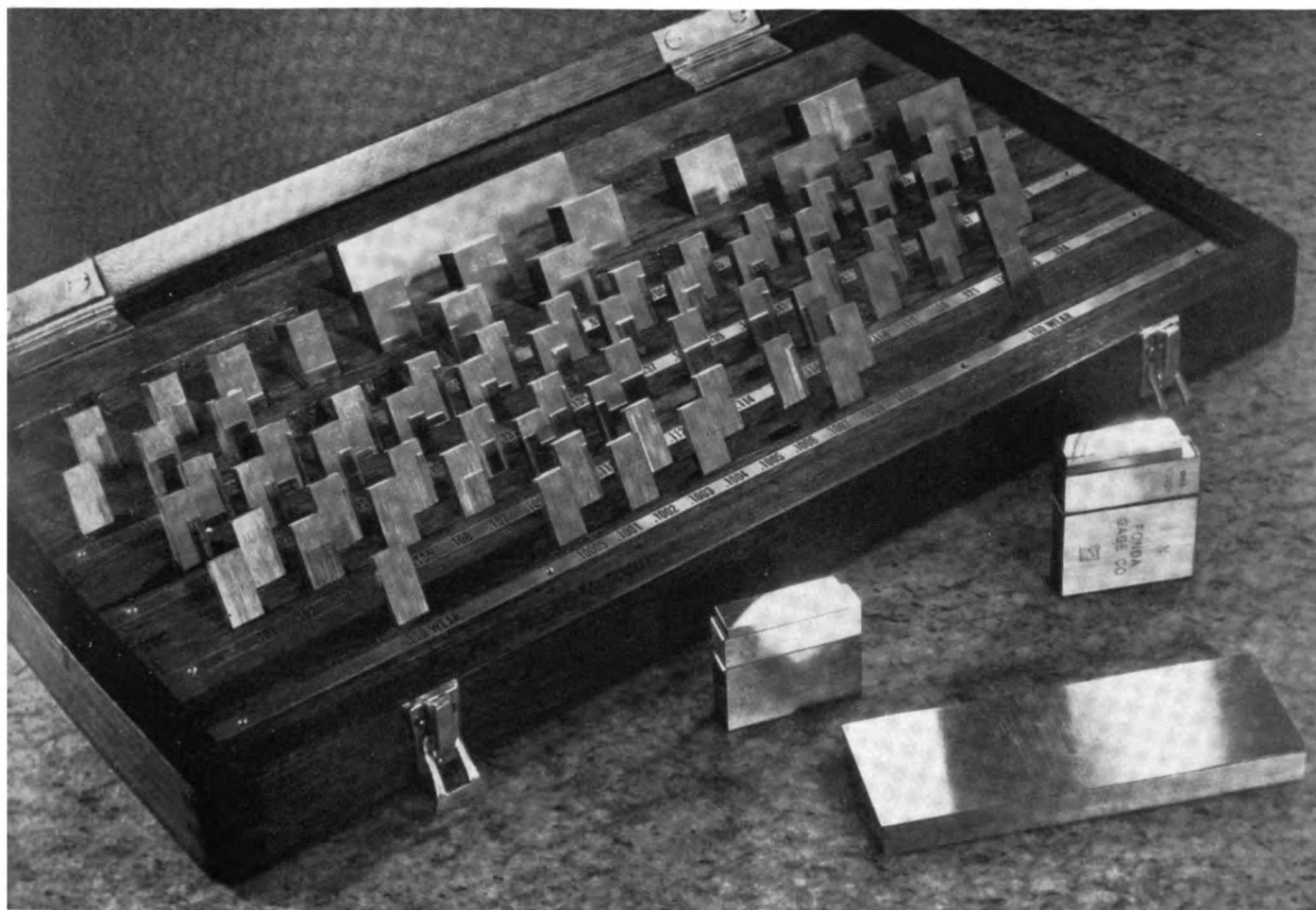


Fig. 19 — The universally accepted gage block represents a convenient form of linear accuracy.

or slip gage, of hardened steel with highly finished faces, Fig. 19, introduced by Johansson more than 50 years ago. The rectangular section of the Johansson gage, in sizes up to four inches, has been found especially suitable for a wide variety of precision measurements.

An important feature of gage blocks and end measures is the ability to "wring" two or more of them together, by bringing their faces into contact with a combined sliding and twisting motion, to form combinations which are strongly adherent. This adherence is due to molecular forces of cohesion. Uniformity of the wringing film is assured by thorough cleaning in benzene and the introduction of a minute amount of kerosene between the surfaces. The minimum film is .0000002" —

.0000003" as determined at the N.P.L. by careful measurement. For all practical purposes, it may be said that the length of a wrung combination of such gages is equal to the sum of their individual sizes, Fig. 20.

**Transfer from Line to End Standards** — As the fundamental units of length are defined by line standards, an essential operation to be performed in calibration of end standards is the transference from line to end measures.

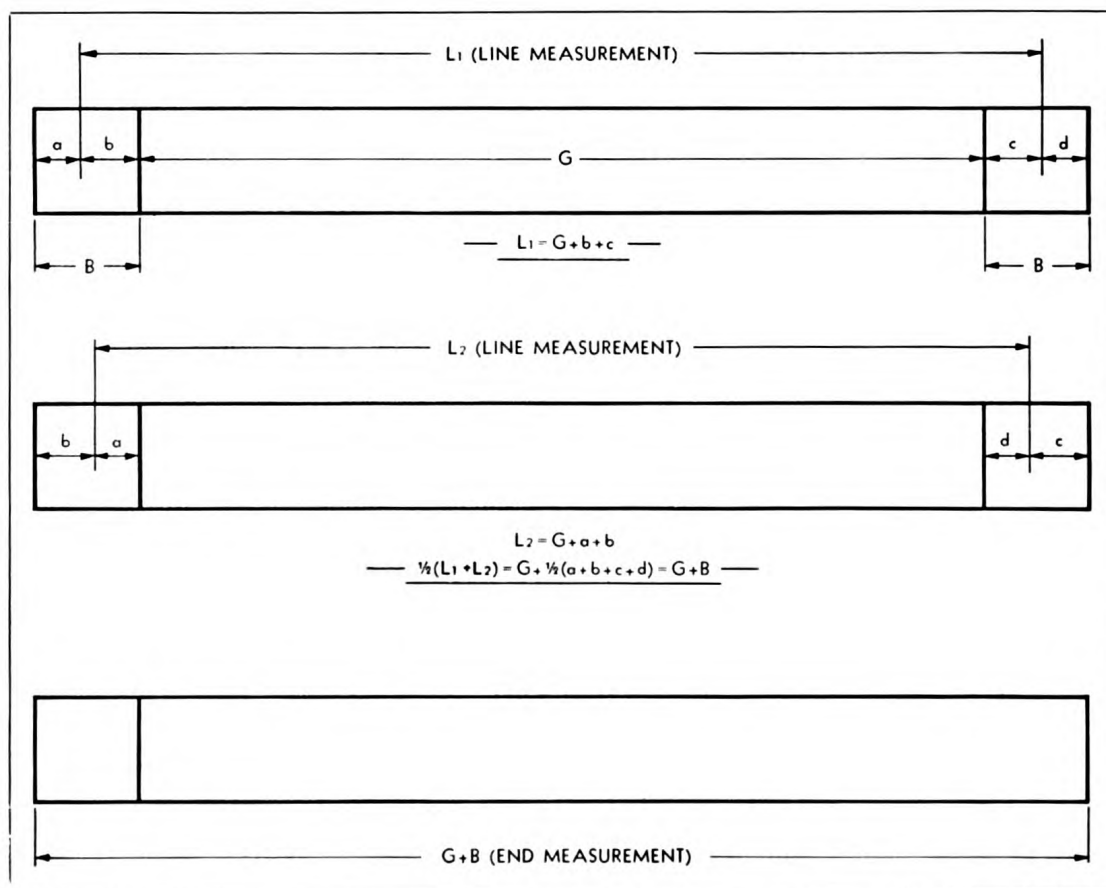
The method devised and used at the N.P.L. for measuring a meter end gage in terms of the line standard is illustrated in its simplest form in Fig. 21. Let  $G$  represent the length of an end gage of nominal length 1 meter less  $\frac{1}{2}$  inch; and  $B$ , the length of each of two nominally  $\frac{1}{2}$ -inch gage blocks. The blocks



Fig. 20 — Except for minute differences of wringing film, combinations of individual gage blocks are as accurate as a single block of equivalent length.

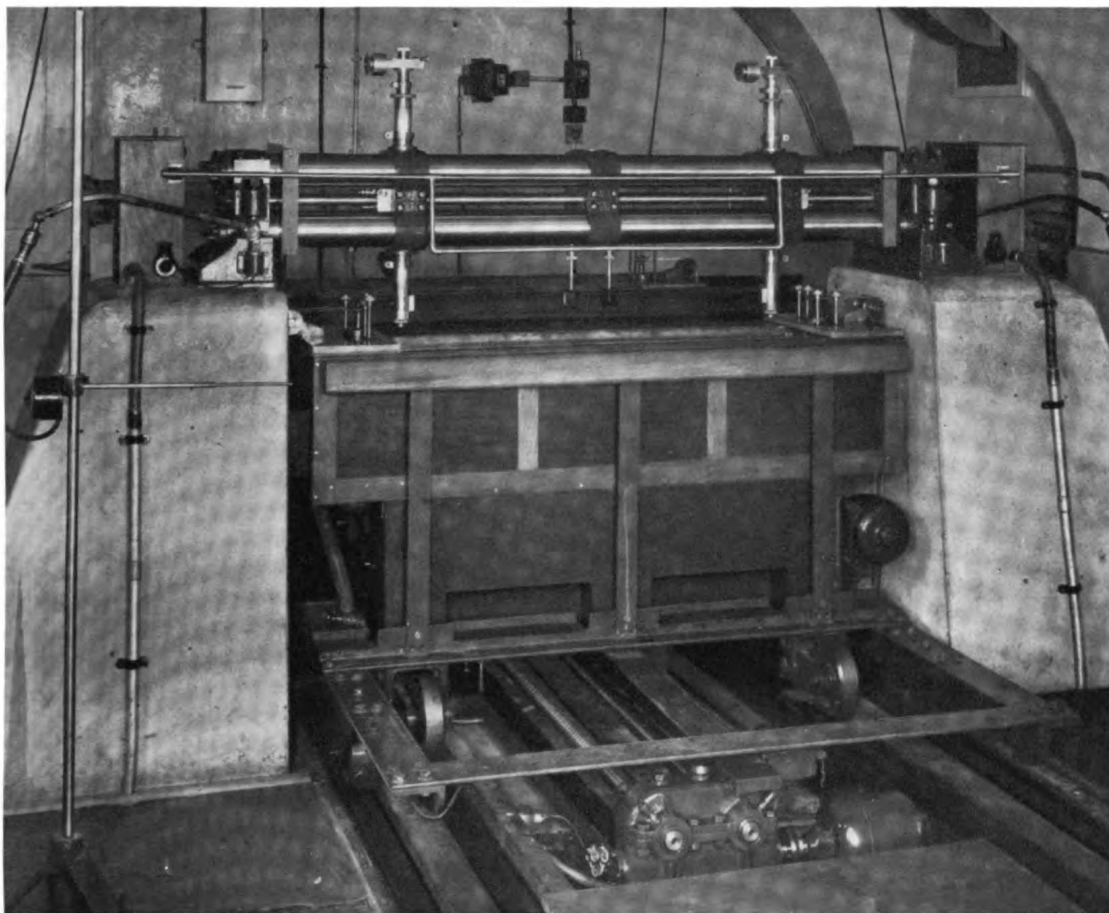
are wrung to the ends of the gage so that their upper faces are in a plane of the gage axis. These faces are polished and each is ruled with a single transverse line in approximately the central position. The distance between the lines is thus about 1 meter, and is measured with reference to the line standard replica of the meter in a line standard comparator, Fig. 22.

On the comparator two microscopes are used, set at a fixed distance apart, to read on the graduation line of the meter standard or the composite gage. The standard and gage are carried on two parallel girders on the carriage of the comparator, which has independent adjustments for aligning the bars and focusing the graduations in the microscopes. The carriage can be moved so as to bring either bar into view under the micro-



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Fig. 21 — Comparison of an end standard to a line standard involves the use of ruled blocks.



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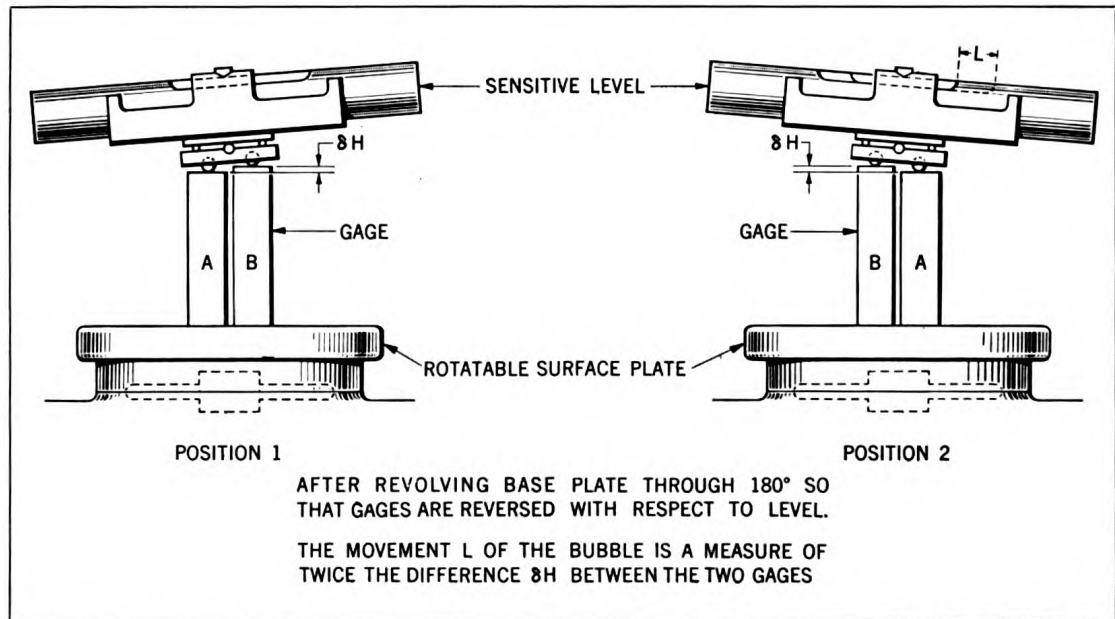
*Fig. 22 — The line standard comparator permits direct comparison of line standards with each other or with end standard fitted with ruled blocks.*

scopes. In the eyepiece of each microscope a reticle bearing two parallel dark lines is adjusted by the micrometer so as to appear symmetrically disposed in relation to the image of the graduation line, first on the meter and then on the composite gage. From the difference between the readings on the two pairs of lines, the distance between the lines on the composite gage may be derived in terms of the meter. The comparator is water-jacketed and remains at a constant known temperature.

Referring to Fig. 21, two combinations of the blocks with the end gage are measured, the blocks being reversed in the second with respect to the first. The average result of the two line measurements is seen to be equal to

the length  $G$  increased by half the sum of the block lengths  $B$ .

Next, the end measure with only one block wrung to it at a time — thus producing a composite end gage nominally 1 meter long in each case — is compared with the meter end gage in a sensitive end-comparator. From these end measurements the average length of the composite bar is again  $G$  increased by half the sum of the block lengths. The length of the gage and the blocks is thus eliminated from the comparisons. The final result gives the length of the end gage in terms of the meter. Transfer from line to end measure for meters and yards is usually accomplished by this method to an accuracy of  $\pm .00001$ , or about 1 part in 4 millions.



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Fig. 23 — Comparison of end gages in the level type comparator of 17,000 magnification, including the doubling effect due to rotation of the base plate. A length difference of .0001" between gages would result in a reading of nearly  $1\frac{3}{4}$ ", thus making it possible to measure differences of one millionth of an inch.

#### Mechanical Comparison of End Standards —

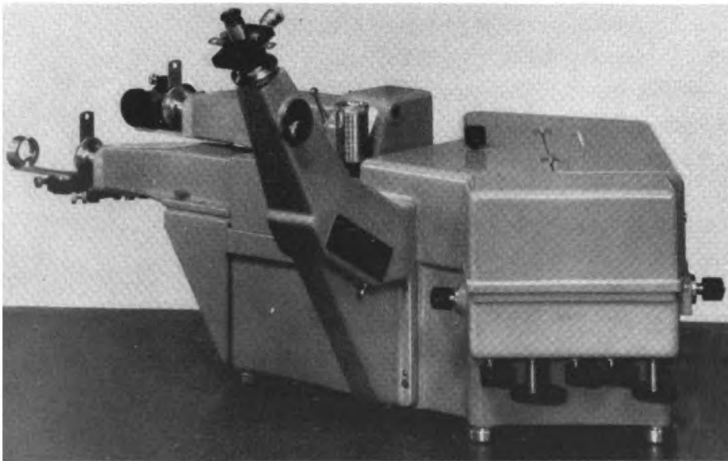
The process of determining the values of end gages representing subdivisions of fundamental units is accomplished by comparing combinations of equal nominal size, Fig. 23. This is done in suitable, highly sensitive comparators or end-measuring instruments.

#### Direct Optical Measurement of End Standards —

As an alternative to the mechanical method, these gages can be directly measured in terms of light waves in an interferometer, Fig. 24. Accuracy by such methods is of the order .0000006". The agreement between this method and mechanical subdivision is generally about one part in a million or better.

**Lead or Micrometer Screw Standards —** The use of an accurate screw thread is a natural development of the search for a length standard capable of infinitely fine incremental division and permitting simultaneous measurement and positioning. Only the screw meets all of these requirements, thus combining static and dynamic measuring effectiveness.

Use of screws for considerable distances was delayed by lack of suitable equipment and methods for producing and measuring them to the requisite accuracy. However, the highly desirable features inherent in the screw as a measuring and positioning element of the Jig Borer and Jig Grinder were sufficiently attractive to provide Moore with the incentive to find ways to overcome the obstacles and to



Courtesy of Hilger-Watt, Ltd., London

Fig. 24 — The gage interferometer is more suitable for measurement of gage blocks, and permits reading accuracy of somewhat less than one millionth of an inch.

produce screws equal in accuracy to gage block combinations capable of the same increments of measurement and of equivalent length, Fig. 25.

Although the method of manufacture of these screws is now well known, the equally complex problem of accurately measuring them may be of interest. This is especially so since they are produced in such numbers that a laboratory method is no longer economical.

**Measurement of Lead** — Commercial lead measuring instruments generally are based on the comparison of the distance between any selected threads and a block or blocks of equivalent nominal dimension. In practice, the first thread at one end of a screw becomes a starting point, successively related to other threads at suitable intervals throughout the length of the screw in comparison with the proper gage blocks. While this method is suitable for occasional use, and admittedly has the advantage of versatility, it is limited by the following factors:

1. Determinations at closely spaced intervals, or thread by thread, necessitate building up stacks of blocks to serve as the standard. This is a tedious and exacting task.
2. Due to lack of squareness of faces to sides, it is virtually impossible to support a long stack of blocks so that the gaging faces are square to the thread axis.
3. While a series of single blocks would minimize the problems of point 2, this system would involve a vast number of expensive gages or limit the measurement to unsatisfactorily long intervals.
4. At best, the procedure is lengthy and the result subject to a strong possibility of variations induced by observer error.

In view of these limitations, plus the fortunate repetitive nature of the work — i.e., the measurement of only  $1\frac{1}{8}$ " diameter, 10-pitch Acme thread — Moore developed the special lead checking instrument shown in Fig. 26.

Essentially, this device provides for the direct comparison of a master screw, in this case the standard, with the screw to be measured, Fig. 27. Reference to the schematic drawing, Fig. 28, shows alignment of

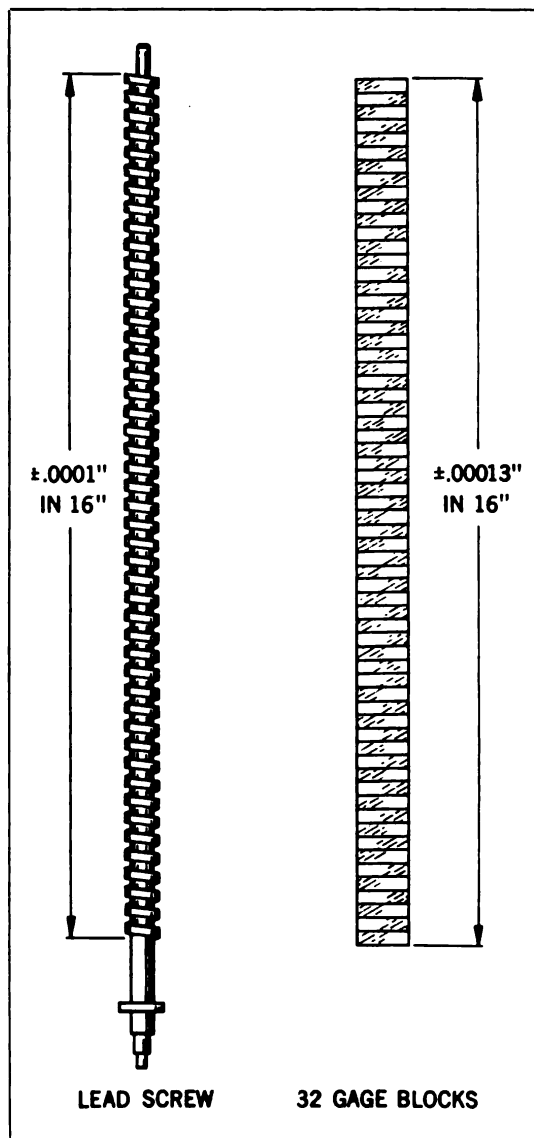
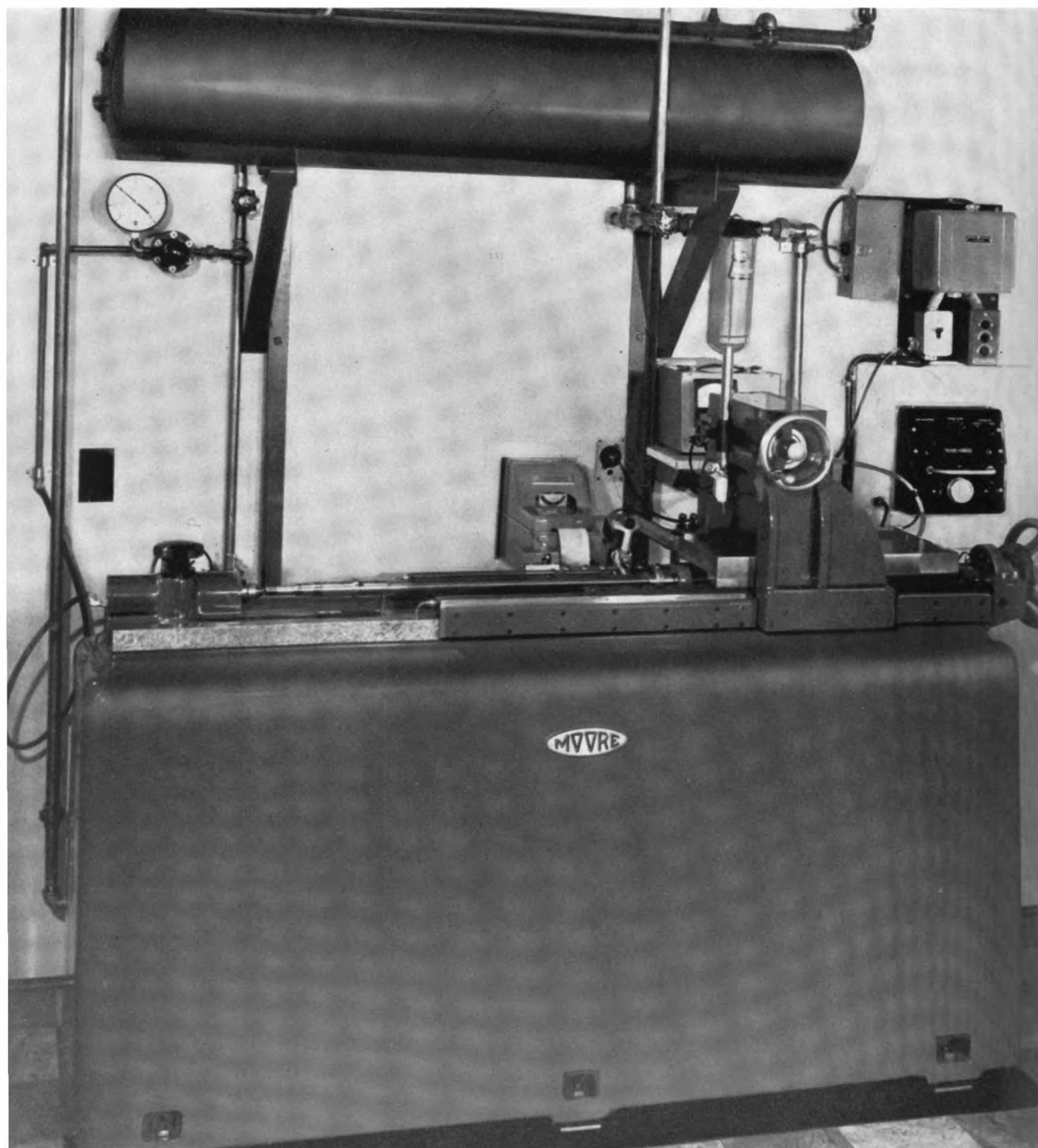


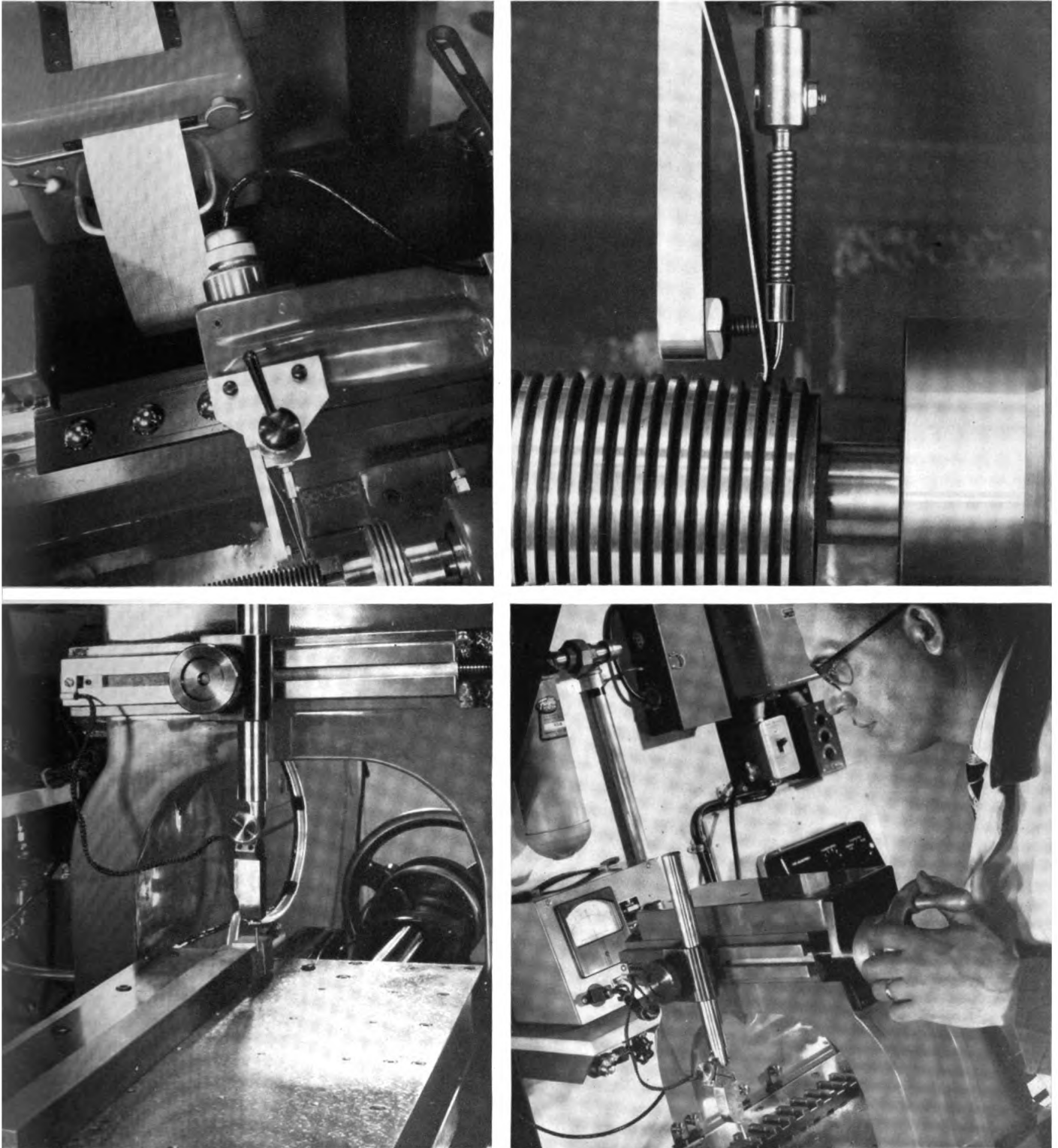
Fig. 25 — The cumulative effect of tolerance on the individual gage blocks, together with the variable of wringing film, does not insure accuracy greater than that attainable with the precision lead screw.

both screws on a common axis. The male center of the master screw provides an axial and radial location for one female end of the screw to be measured. The outboard end of the latter is engaged by a pneumatically loaded center. This establishes its alignment and maintains axial thrust, which is opposed by the thrust collar of the master screw. In this relationship, there can be no relative axial move-



*Fig. 26 — This special-purpose instrument measures Moore lead screws to .00001" and also permits direct comparison of its master screw to various line and end standards.*

## THE FOUNDATION OF ACCURACY



*Fig. 27 — Details of the lead screw measuring machine showing relationship of probe to thread and comparison of various gages to the master screw by electronic indicator.*

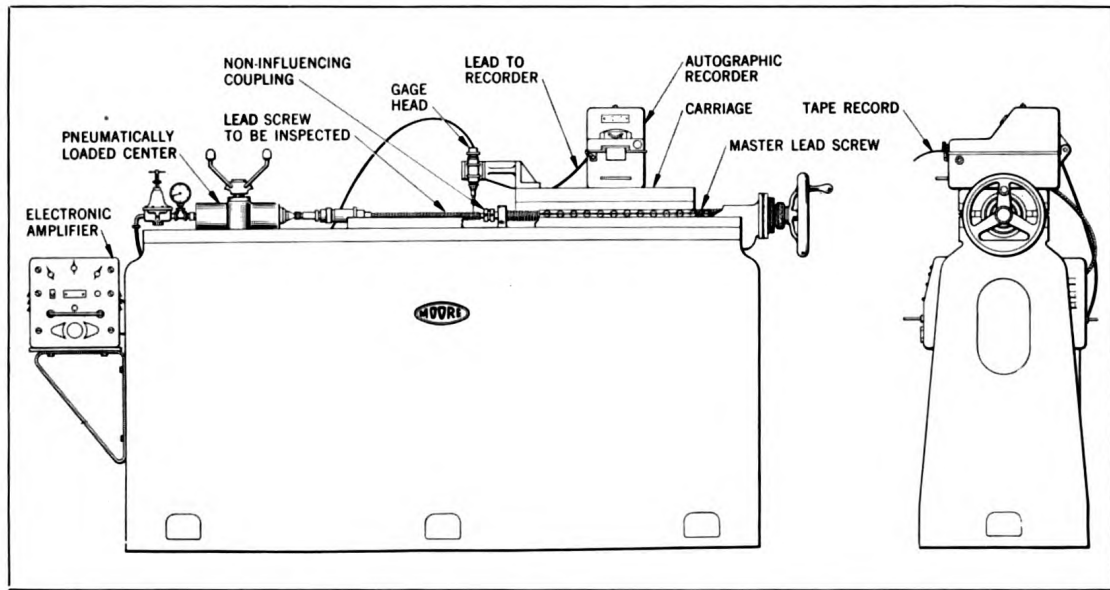


Fig. 28 — Construction principles of the Moore Lead Measuring Machine.

ment between the screws. A non-influencing bellows coupling locks them together so that, in effect, they may be considered as one.

The carriage, moving on anti-friction ball-bearing ways, is related to the master screw by means of a nut, so that rotation of the screw moves the carriage in a line parallel to the screw axis.

Supported from the carriage, an indicator point contacts the thread flank of the screw to be measured, and is displaced by any deviation in lead between the screws as they rotate. A rectilinear recorder, Fig. 29, produces an autographic record of the displacement of the indicator point in a ratio of 5,000 to 1.

This method provides the following advantages:

1. The *continuous*, effective lead of the screw is measured throughout the entire length of the screw.
2. Periodic error, or drunkenness, is shown as a repetitive deviation superimposed on the curve representing lead.
3. The information is produced in the form of an autographic chart which provides a permanent record, uninfluenced by an observer, Fig. 30.
4. The entire procedure of comprehensively measuring a screw of 18" requires only a few minutes' time.

Midway in the development of this instrument, it was discovered that the N.P.L. had for years been using a virtually identical method of thread measurement, with highly



Courtesy of Taylor, Taylor and Hobson, Ltd.,  
Leicester, England

Fig. 29 — The recording portion of the Lead Measuring Machine produces an autographic record of the screw being measured.

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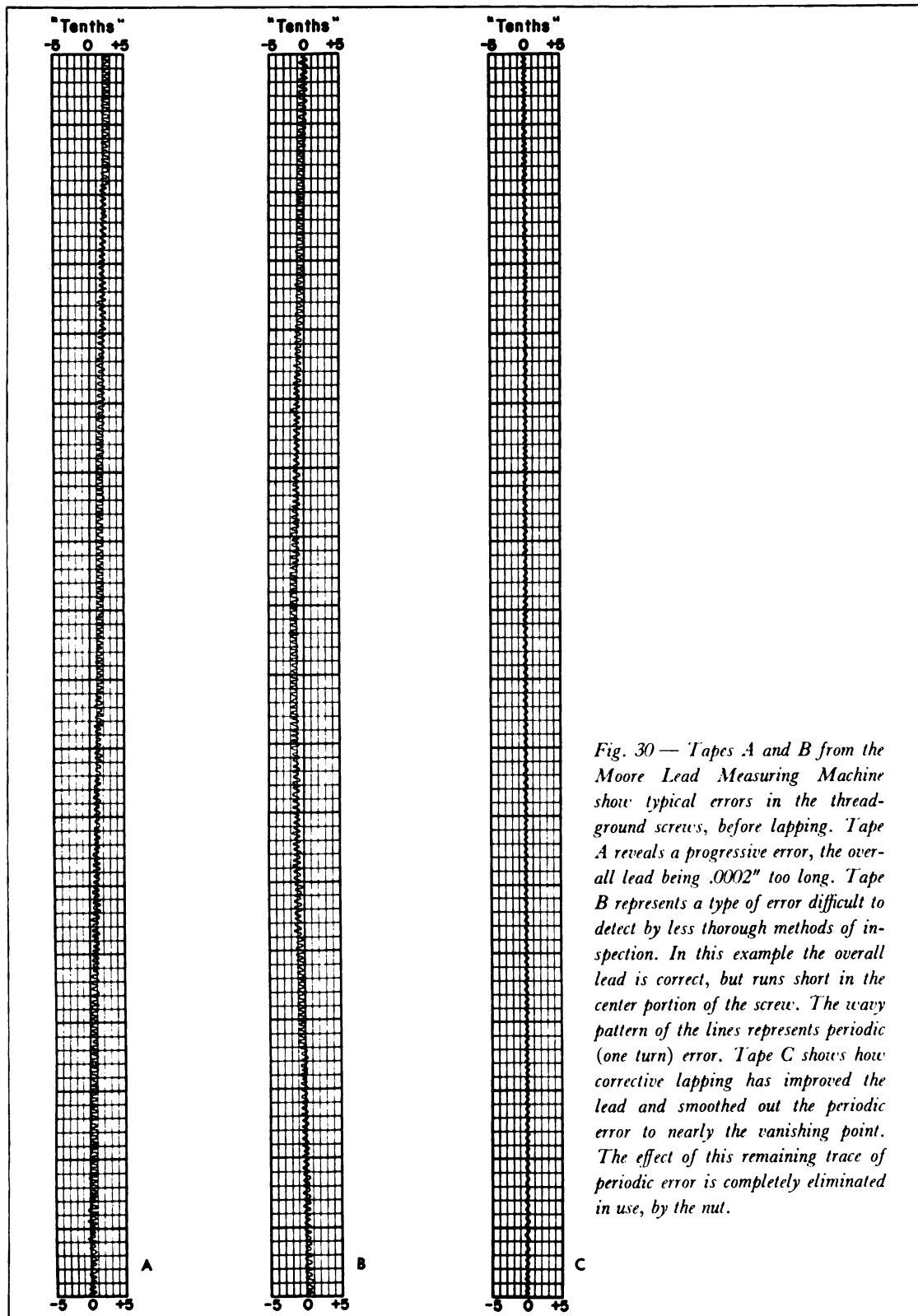


Fig. 30 — Tapes A and B from the Moore Lead Measuring Machine show typical errors in the thread-ground screws, before lapping. Tape A reveals a progressive error, the overall lead being .0002" too long. Tape B represents a type of error difficult to detect by less thorough methods of inspection. In this example the overall lead is correct, but runs short in the center portion of the screw. The wavy pattern of the lines represents periodic (one turn) error. Tape C shows how corrective lapping has improved the lead and smoothed out the periodic error to nearly the vanishing point. The effect of this remaining trace of periodic error is completely eliminated in use, by the nut.

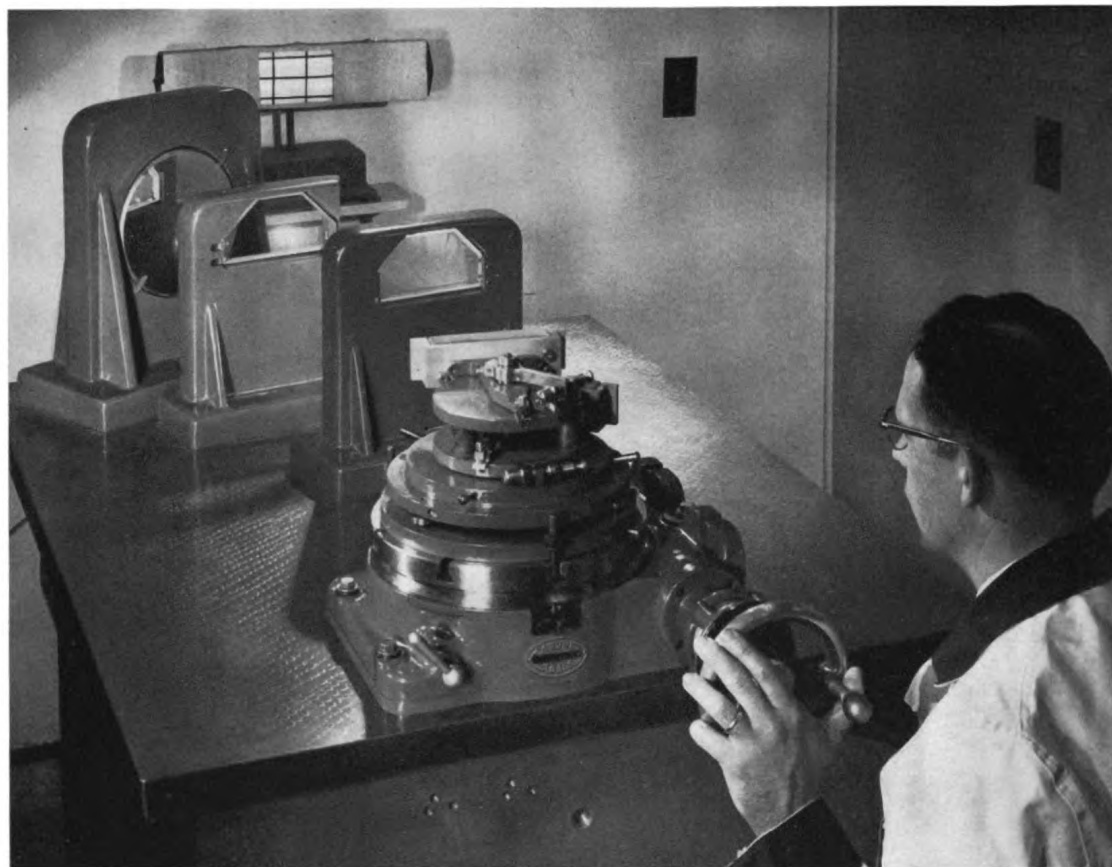


Fig. 31 — The first industrial use of the O'Donnell interferometric method of angular measurement.

satisfactory results. The only essential difference was the addition of a gear ratio between the master and the screw to be measured. This ratio was made necessary by the variety of pitches encountered in the Laboratory's work.

It was, therefore, quite natural in seeking an authority for the accuracy of the master screw, to take it to the N.P.L. for measurement and certification.

**Angular Measurement** — Angular measurement, or division of the circle into precisely equal angular spacing, represents an entirely different set of problems from those encountered in the case of linear measurement. One of the most common applications is in the measuring and/or positioning system of a rotary table.

Since it is axiomatic that it is impossible to work more accurately than one can measure,

the lack of a necessary differential here constituted a serious limitation in the attempt to manufacture rotary tables to a high degree of accuracy.

Although there are accepted methods for such measurements, including the theodolite, auto-collimator and precision polygon, it remained for T. J. O'Donnell, of the University of Chicago,\* to develop an ultra-precise, rapid method of angular measurement based on an adaptation of the Michelson interferometer. This instrument is extremely flexible in application and is capable of dividing the circle into divisions as small as may be required. It has the additional advantages of requiring no master and of checking itself. Applied industrially for the first time to measuring the accu-

\*The authors acknowledge the cooperation of the University of Chicago for some of the material pertaining to angular measurement appearing in this chapter. See page 53.

racy of rotary tables by Moore, this instrument appears as shown in Fig. 31.

Since this represents an entirely new method of applying light-wave measurement to angular determination, a description of the instrument and its operation is warranted.

The optical components consist of five pieces of special glass, three of which are aluminized on their flat surfaces to form fully reflecting mirrors, shown at A, B and C, in Fig. 32. A single piece of glass, its faces lapped flat and parallel, is cut to form two pieces of identical thickness, one of which is mounted at D. The second piece is half-coated, or aluminized, to the extent that it will reflect approximately half of the light striking its surface and will transmit the rest.

Members A, D and E are mounted in frames, immovable except for a slight adjustment for initial optical alignment. Mirrors B and C are so mounted on the rotary table that B can be angularly displaced in relation to C by any desired amount, or both can be angularly moved, as a unit, in relation to the table.

A beam of light, XY, from the monochromatic light source Z, strikes the half-coated surface of the split-plane mirror E and splits into the twin half-beams X and Y. Half-beam X is reflected through the compensator D reversed on the face-coated mirror A, and passes in the opposite direction through compensator D again to impinge on the half-coated face of E. Meanwhile, half-beam Y passes through the split-plane mirror E, is reflected from the front face mirror B, and passes again through the split-plane mirror to impinge on its half-coated face. The sole purpose of the compensator D in the optical circuit is to equalize the optical path of the twin half-beams so that each will have passed through the same thickness of glass before re-combining on the half-coated face of E. In this way compensation is made for the difference in refractive index between glass and air.

With mirror B in the position shown, an observer at W will see circular fringes in a bull's-eye pattern of alternate light and dark circles, Fig. 33, apparently on the face of the

split-plane mirror E. They actually are at infinity. Lateral movement of the eye will cause no change in this pattern. Angular displacement of mirror B by even a fraction of a second will cause the fringes to change in number during a lateral movement of the eye; the rings growing out of the central spot, or shrinking into it, depend upon whether B was moved in a clockwise or counter-clockwise direction.

By establishing limits of lateral movement of the eye, employing a pair of suitably spaced vertical fiducial lines for the purpose, the value of one changing fringe can be fixed in terms of seconds. In practice, the spacing of these lines is accomplished as follows:

1. Assume that the desired ratio is 1 second = 1 fringe.
2. Stretch block threads across the face of the light source so that they appear to the observer as vertical, parallel lines.
3. Adjust the space between the lines so that a displacement of mirror B by one second, as read on the rotary table, causes a change of one fringe. Lateral movement of the eye causes the pattern to move the distance between the lines. The direction of displacement is also determined in this step.
4. Although this empirical value may not be exact, subsequent measurement of the angle during inspection of the table is self-checking and permits final correction of this spacing.

Having thus established the value of fringes in terms of seconds, inspection of the accuracy of the rotary table is accomplished in the following manner:

1. Assume that the accuracy of a rotary table is to be determined through  $360^\circ$ , at  $30^\circ$  intervals. Any other interval such as  $1^\circ$  may be used, if desirable.
2. With the table at  $0^\circ$ , set mirror C in the same position as B in Fig. 32, or to show zero fringe change.
3. Without disturbing the relationship of C to the table, rotate the latter counter-clockwise exactly  $30^\circ$ , as read on its graduations. Mirror B is now set to zero fringe change and both B and C are in the relation shown in Fig. 32, the angle between them representing the value of  $30^\circ$ , as read on the table.

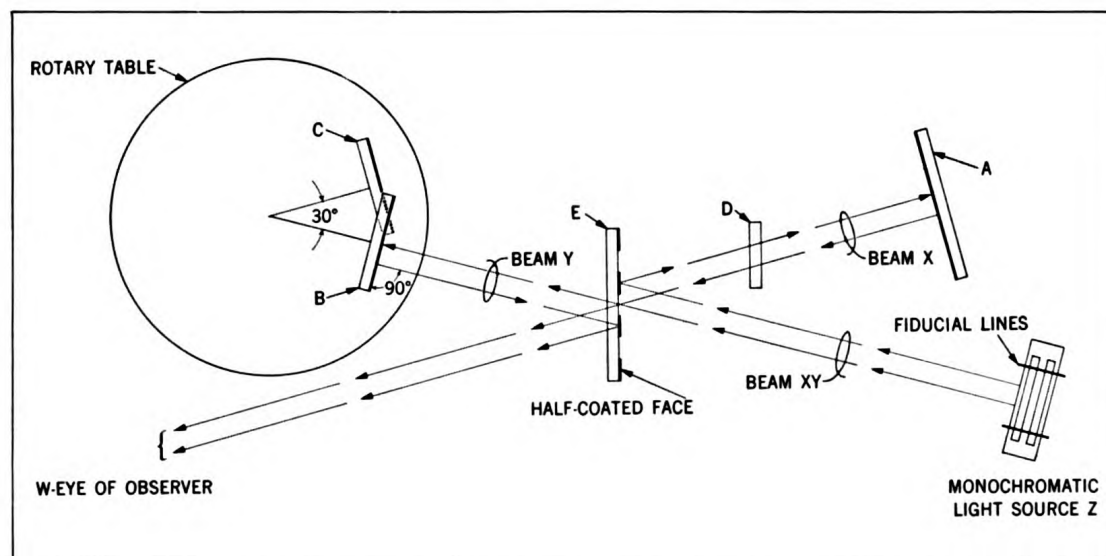


Fig. 32 — Optical principles of interferometric angular measurement.

4. Move both mirrors as a unit, without disturbing the table setting, until C is positioned to zero fringe change. Table is now set at  $60^\circ$ , which should bring B to a zero fringe change position, if the value  $0^\circ - 30^\circ$  on the table were exactly equal to that from  $30^\circ - 60^\circ$ . Any difference can be read directly, in seconds, by counting changing fringes and recording the result.
5. Step 4 is repeated, advancing the table  $30^\circ$  at a time, until the necessary 12 determinations have been made.
6. The results, tabulated in Fig. 34, are added and the sum divided by 12. This value is the error in setting the angle between the mirrors and may be corrected mathematically in calculating the results, or the spacing of the mirrors may be altered by the requisite amount.

ANGLE IN DEGREES	STEP ERROR RELATIVE TO ANGLE B-C	TOTAL $360^\circ$ CUMULATIVE ERROR	COMPENSATOR $1/12$ TOTAL ERROR PER $30^\circ$	ACTUAL ERROR RELATIVE TO $30^\circ$ ABSOLUTE
30	+2.0	+2.0	-0.42	+1.58
60	0	+2.0	-0.83	+1.17
90	+0.5	+2.5	-1.25	+1.25
120	0	+2.5	-1.67	+0.83
150	-1.0	+1.5	-2.08	0.58
180	0	+1.5	-2.50	-1.00
210	+3.0	+4.5	-2.92	+1.58
240	-1.0	+3.5	-3.33	+0.17
270	0	+3.5	-3.75	-0.25
300	0	+3.5	-4.17	-0.67
330	+2.0	+5.5	-4.58	-0.92
360	-0.5	+5.0	-5.00	0

Fig. 34 — As indicated in this table, final correction of mirror angle is not necessary, as any small deviation from the nominal is arithmetically corrected in tabulation.

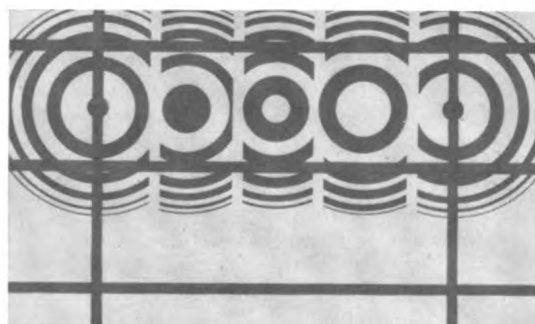


Fig. 33 — Circular fringes are clearly defined and easily read.

From the foregoing it may be observed that, in effect, the interferometer is used as a pair of dividers in stepping off the spacing of the table. This comparison may be clarified by referring to Fig. 35. With the dividers set to match the graduation at  $0^\circ$  and  $30^\circ$ , they are then compared to the  $30^\circ$  and  $60^\circ$  sector, and the difference, if any, noted. One leg is then set on the  $60^\circ$  graduation and the other compared to the  $90^\circ$  line. This procedure is repeated until the circle has been closed. It will also be observed that any error in the initial setting of the dividers can be detected upon closing of the circle; otherwise, return to zero. This error may then be corrected arithmetically in tabulating the results, or physically, by readjustment of the dividers and by a repeat of the check.

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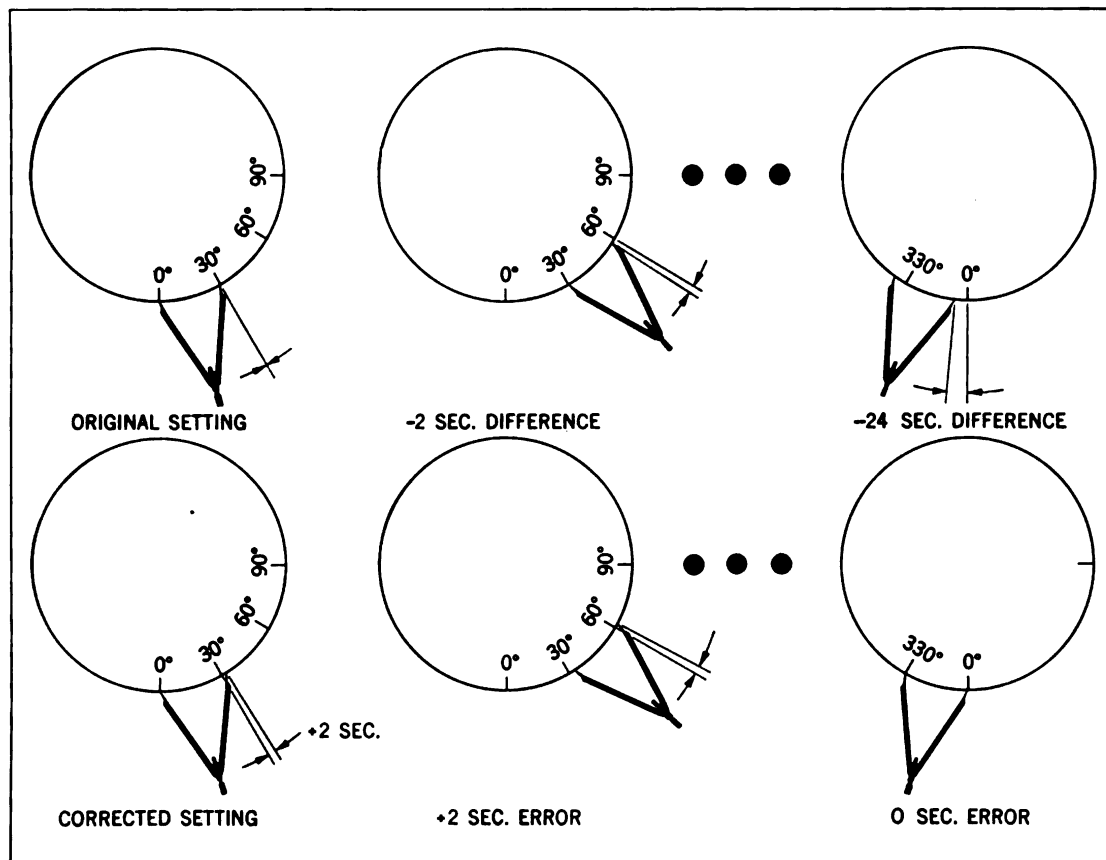


Fig. 35 — Dividers used to compare the value of circular divisions.

In this application the interferometer utilizes, as a standard of comparison, the fixed value of monochromatic light waves, self-checked by the final closing of the circle.

The purpose of this chapter has been to give some insight into the problem of estab-

lishing fundamental standards of accuracy as foundations upon which all performance accuracy determinations must rest. In subsequent chapters, the relation of these standards to the design and construction of *engineered* locating equipment will be developed.

### Acknowledgments

*The authors wish to express their appreciation to Sir Edward Bullard, Director of the National Physical Laboratory, Teddington, Middlesex, England, and to Mr. F. H. Rolt who, until his recent retirement, was Superintendent of the Metrology Division, for having made possible a series of conferences with various staff members. Special thanks are also due to Dr. H. Barrell, the present Superintendent of the Metrology Division, and to Dr. Evans and Messrs. Taylerson, Oakley and Robinson, who directly contributed much of the material in this chapter.*

*The authors also wish to express their appreciation to Dean W. Bartky of the University of Chicago for having made possible a series of conferences with Mr. T. J. O'Donnell, and to Mr. O'Donnell for having made available his technique of interferometric angular measurement.*



*Engineered Location Equipment Standards.*



## ENGINEERED LOCATION EQUIPMENT STANDARDS

THE TOOLMAKER'S sequence of locating, machining and inspecting, described in Chapter 2, is also followed in *engineered* locating methods, but the concept differs greatly:

*Holes may now be precisely located, accurately machined and easily inspected as progressive steps of the same operation, rather than as separate operations!*

The essence of the Jig Borer's and Jig Grinder's contribution to the accuracy and efficiency of this operation can be simply stated as follows:

1. The workpiece is attached to the machine table throughout the operation.
2. Location of holes in relation to the spindle axis is established by the rectilinear movement of the table, controlled by an accurate measuring system, Fig. 36.
3. Holes generated by boring or grinding are coaxial with the machine spindle.

Several important advantages result directly from this relationship of workpiece to machine:

1. In addition to a vastly improved accuracy in each phase of the operation, as compared with toolmaker locating methods, the transition error (Chapter 2) is now entirely eliminated.
2. Overall work accuracy is so consistently high that interchangeability becomes a commonplace reality.
3. The cost of precision is greatly reduced, because of the increased efficiency.
4. Machine operators, requiring less background and training than the toolmaker, can relieve him of the once tedious job of location.

No evolution so significant as that from toolmaker working with *improvised* methods to machine operators using *engineered* location methods can be effectively accomplished without a thorough understanding of the principles upon which this new concept is based. These principles should be grasped by management, designer, toolmaker and machine operator, in order that each can make better use of them.

Let us first consider the design philosophy

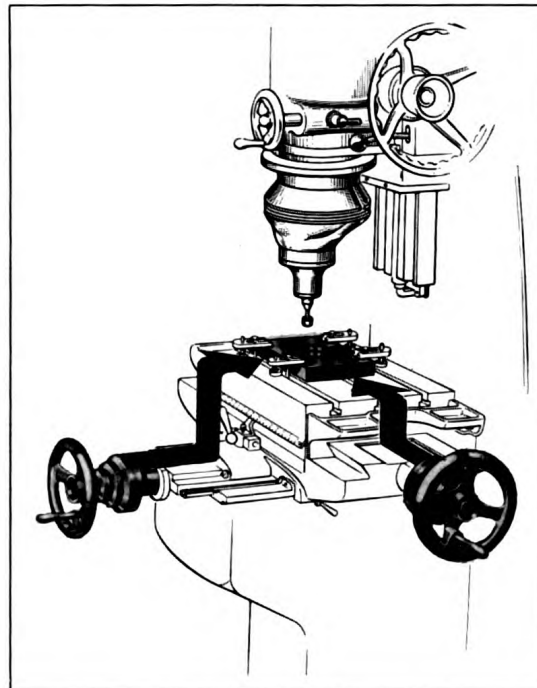


Fig. 36 — The machine represents the physical embodiment of the coordinate system.

and construction principles affecting the accuracy of the machine. This is necessary in order to justify the dependence that must be placed upon the machine as the nucleus of precision location. Familiarity with the equipment will also serve to insure its efficient and effective use. Insufficient knowledge of precision location has sometimes resulted in equipment being utilized at less than its maximum potential. For example, some Jig Grinder installations have been made solely for salvage operations, where toolmaker methods have resulted in locational errors beyond acceptable limits. Obviously, this is a case of "locking the barn door after the horse has been stolen."

The fundamental purpose of the Jig Borer, the Jig Grinder and the Form Grinder is to machine to accurate location; therefore, the same basic design principles apply to each. This relationship is extended to include a parallel standard of accuracy. Somewhat greater accuracy may be attained in grinding, simply because this operation on hard material is inherently better suited to dimensional control than is the machining of soft material.

In presenting a solution to the overall problem of location, it must be recognized that while the *basis* of accuracy lies in the dimension-controlling measuring system of the machines, including the template of the Form Grinder, the transfer of this accuracy to the workpiece is attended by the possible loss of a portion of this accuracy every step of the way. This applies not only to the function of the machine itself, but to the tooling and methods employed in its operation.

The Form Grinder, Fig. 4, is not based on the rectangular coordinate principle and, therefore, differs in the physical arrangement of its critical members. The means employed in assuring its accuracy differ in detail from those of the Jig Borer and Jig Grinder, and will be outlined in Chapter 11.

The following analysis shows the effective defense that has been erected against the inescapable sources of error inherent in the toolmaker method of location.

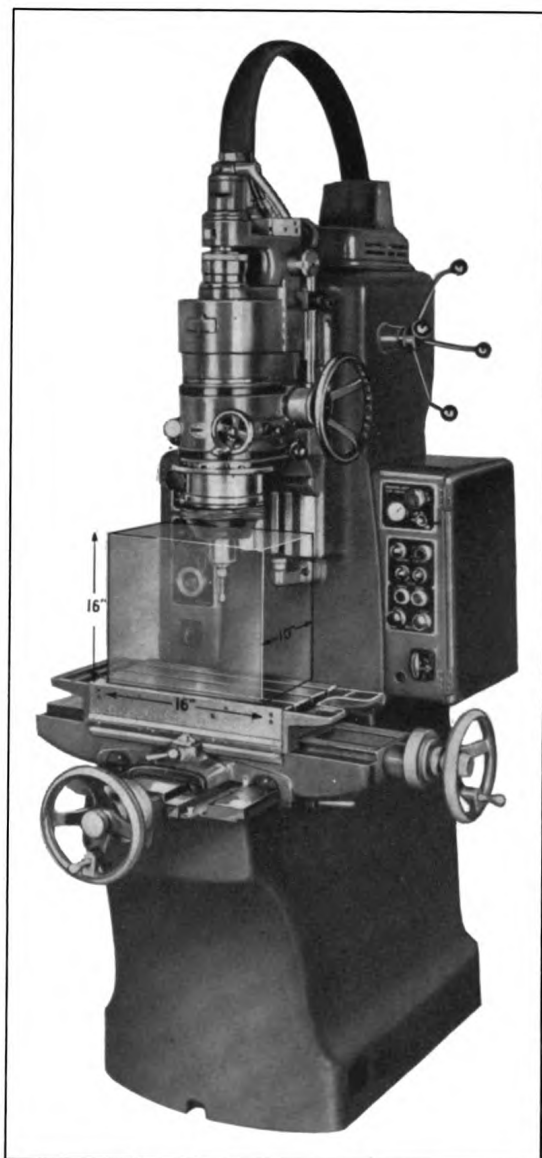


Fig. 37 — The culmination of all machine accuracy is represented by this imaginary cube.

**The Cubic Concept of Accuracy** — Since a hole must have depth, accuracy in one plane is not sufficient! Moore has coined a phrase, "The Cubic Concept of Accuracy," in projecting this requirement to include the space bounded by the vertical as well as the horizontal travel limits. It is within this critical three-dimensional space that the accuracy of the measuring system must be transferred to the work, Fig. 37.

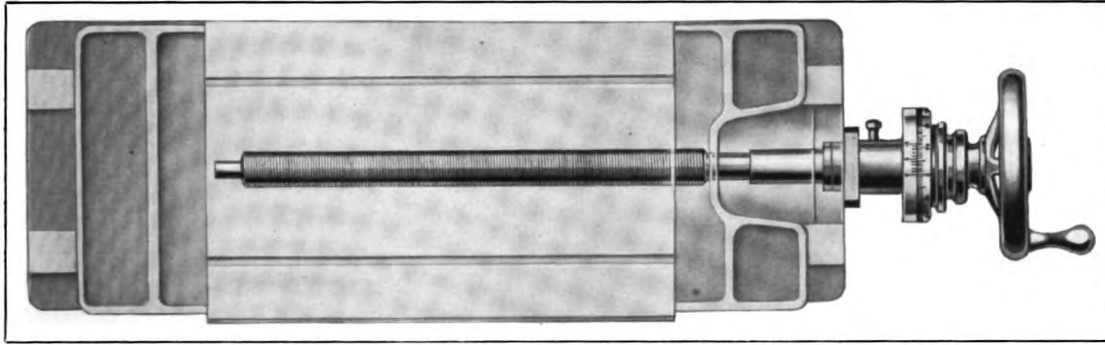


Fig. 38 — Linear measurement, or positioning, controlled by accurate lead screw set from a dial.

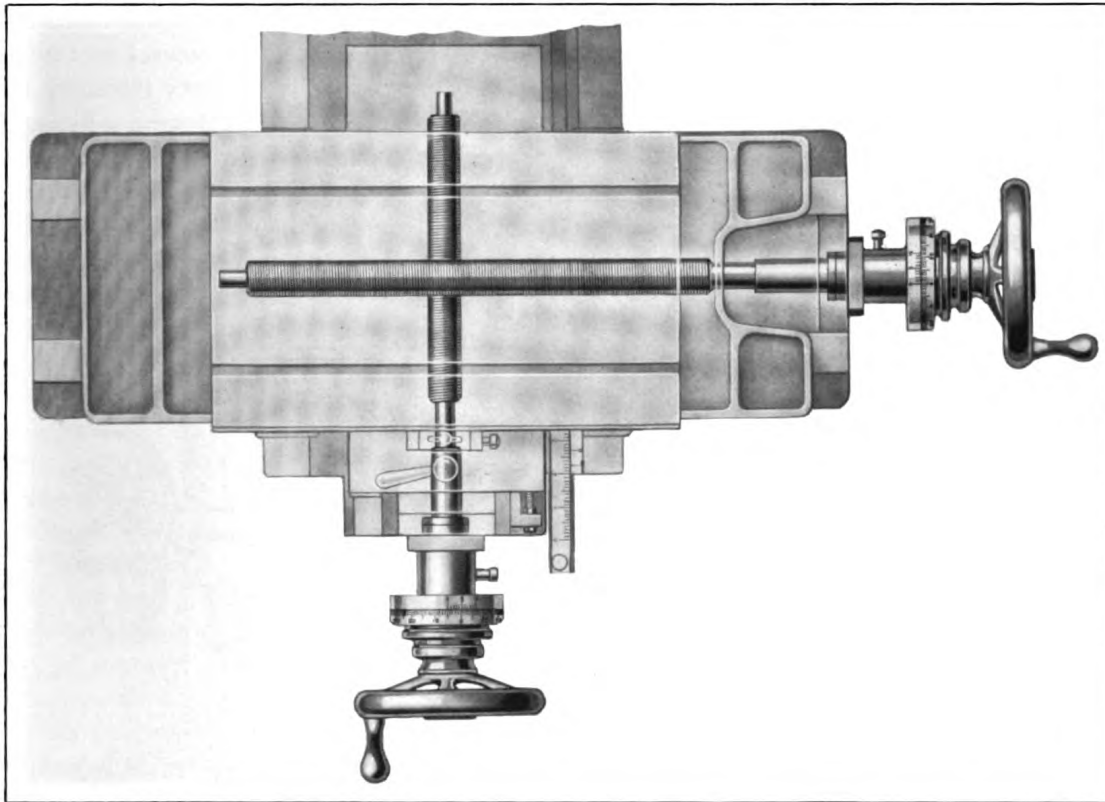


Fig. 39 — Combination of two directions of linear travel at  $90^\circ$  provides rectilinear positioning.

To accomplish this, three basic accuracies are required:

1. The linear accuracy of the lead screw measuring system (Chapter 3), Fig. 38.
2. The rectilinear accuracy of longitudinal and cross travel in the horizontal plane ("squareness"), Fig. 39.
3. Perpendicular accuracy in a vertical plane, Fig. 40.

In order to visualize the means by which this requirement is attained, and at the risk of over-simplification, both the Jig Borer and the Jig Grinder can be temporarily considered as consisting of but two basic elements:

1. A vertical spindle for machining.
2. A horizontal table for work positioning.

The function of all other machine members is thus merely contributory.



Fig. 40 — The perpendicularity (squareness) of the machine spindle is checked by a master square.

**Geometric Accuracy** — The ability to move the machine table an accurately measured distance in two directions of travel, each in exact  $90^\circ$  angular relationship to the other, permits positioning directly to coordinate dimensions. Thus, in effect, the machine is the physical embodiment of the coordinate locating system. In this respect, it is dependent for its accuracy, in the horizontal plane, upon the combined linear and rectilinear accuracies.

Implied in the description of coordinate location is a reference or datum point, from which all measurements are made. The intersection of the vertical spindle axis with the horizontal plane logically provides this point, Fig. 41. Also, it introduces the additional element of true perpendicularity, and thus, the geometry of the cube.

Perpendicularity must be maintained in spite of the relative, vertical movement between the quill, which contains the spindle, and its supporting housing. This movement is necessary to feed the tool into the work. Also, a vertical, positioning movement is re-

quired between the housing itself and the column in order to accommodate workpieces of various heights without excessive projection of the quill.

Recognition of this cubic concept governs the design and workmanship of all functional parts affecting the accuracy of Moore machines. The mounting and slide-way surfaces of all castings are hand scraped to accurately establish their geometry and fit to mating parts. Bores which support members such as the quill and lead screws are precisely aligned. The culmination of these efforts, the completed machine is carefully checked by methods developed especially to reveal any deviation from true cubic accuracy (Chapter 3).

**Performance Accuracy** — Having satisfactorily passed such an inspection is not, in itself, however, adequate assurance that the machine will produce work of commensurate accuracy. Performance accuracy can, of course, be proved in practice, or more con-

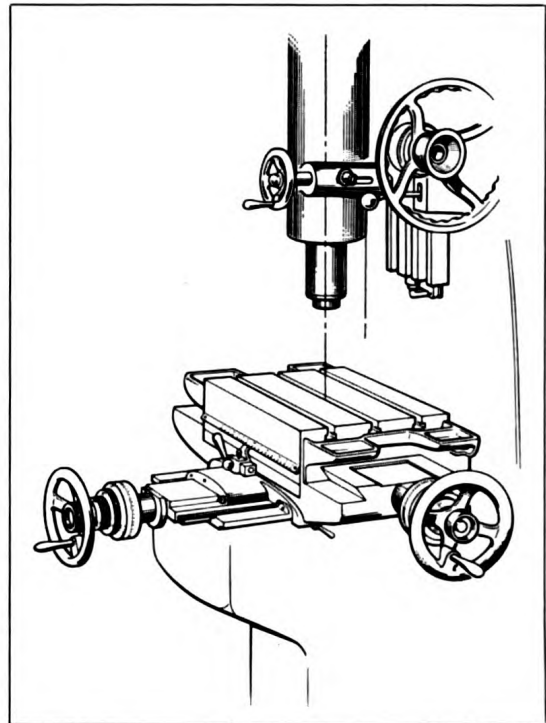


Fig. 41 — Intersection of the spindle axis with the horizontal plane of the measuring system provides the reference or datum point for coordinate location.

vincingly by an analysis of factors capable of introducing operational errors, and how they are coped with in design and construction.

The following list classifies sources of operational error possible in an otherwise geometrically accurate machine:

1. Uncontrolled, relative movement between machine members.
2. Displacement due to the action of clamping or locking devices.
3. Deflection resulting from cutting pressure.
4. Temporary instability as a result of thermal expansion.

Satisfactory means have been evolved for combating errors from these sources and will be discussed in the same order as above.

**Relative Movement** — Uncontrolled, relative movement between machine parts is most likely to occur at points where controlled movement must be provided. For example, the movement of both the slide on its base and the table on the slide must be purely linear, with no sideways displacement or twisting.

In addition to accurately matched and closely fitted slide-way surfaces of adequate proportions, fundamental design concept plays an important role in restraining random movement.

Consolidation in Moore machines of all slide-ways into a close-coupled relationship with the workpiece is an example. This type of construction provides the maximum rigidity of support, and greatly minimizes the adverse effect of any undesirable movement which might ultimately develop as a result of wear.

Alternative design, incorporating one travel of the rectilinear movement into the spindle support, presents problems of parallelism, rigidity and exaggeration of any random movement within this assembly. That is because of its remoteness from the surface of the work.

Limitation of spindle movement to rotation within the quill\* involves elimination of any radial looseness such as is possible with a journal bearing. Preloaded ball bearings provide the most effective support, due to the

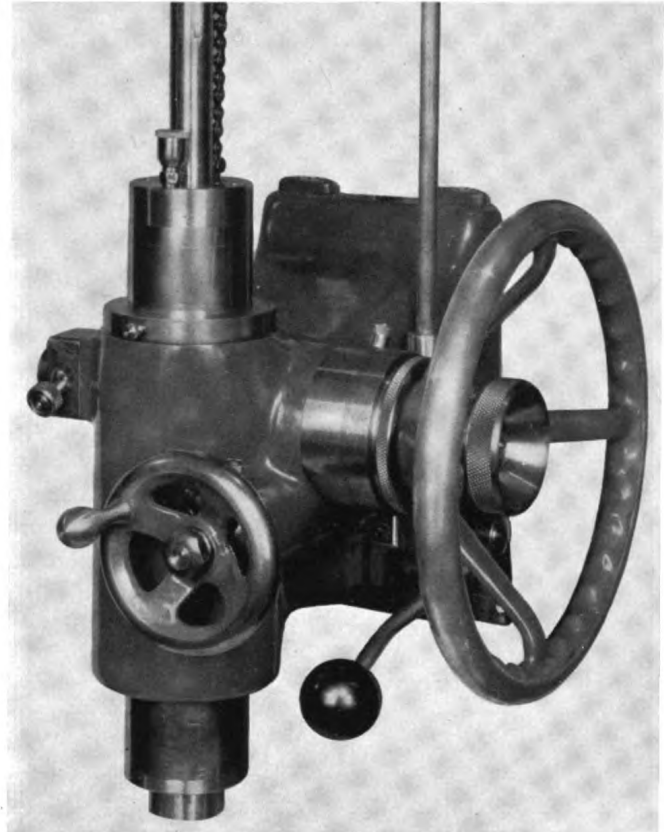


Fig. 42 — Quill and quill bushings are hardened, ground and lapped to a gage fit. Setting the rack below the surface of the quill eliminates slot in the bushing and facilitates line lapping of a true, round hole in both upper and lower bushings.

necessarily wide range of speed and variation of load. Vertical movement of the spindle assembly, in Moore machines, takes place between male and female, hardened, ground and lapped cylindrical surfaces of generous proportions, Fig. 42. These members are so accurately fitted that shake or looseness is effectively prevented.

The apparent inconsistency in avoiding a similar bearing for spindle rotation can be explained by pointing out that working conditions differ greatly. Surface speed of rotation is high and would require an appreciable

\* Although the Jig Grinder does not have a member which can properly be called a quill, its corresponding assembly presents the same problems of alignment. In order to continue this simultaneous discussion of both machines, this variation in nomenclature will be temporarily ignored.

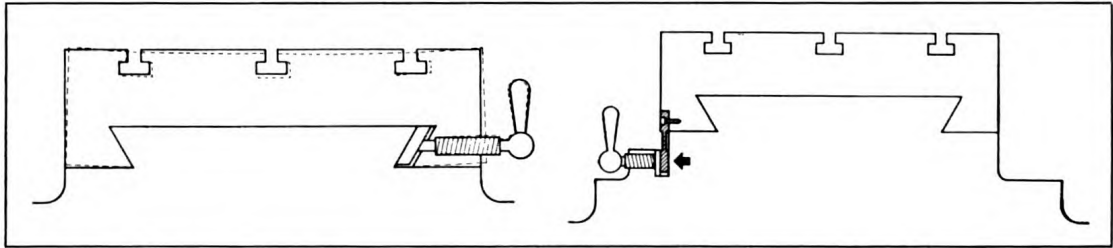


Fig. 43 — Clamping against gibs (left-hand view), although conventional in many machines, is not sufficiently accurate for locating machines like the Jig Borer, Jig Grinder, Form Grinder or Measuring Machine. Spring and shift of all related parts can easily introduce a table movement of .001". A special clamping blade on all Moore machines permits rigid locking but is transversely flexible enough to eliminate displacement of the table.

running clearance and therefore an oil film of sufficient thickness to be displaceable under radial load. The slow, sliding movement of the quill permits such a close fit that only a molecular oil film separates the surfaces. No working load during operation of the machine can possibly displace or rupture this minimum film.

Linear ball bearings, offering the apparently attractive possibility of preload as an alternative sliding bearing, unfortunately move approximately half the distance of the sliding member they support. As a result, the point of support can never be brought as close to the point of tool thrust as can a cylindrical supporting bore.

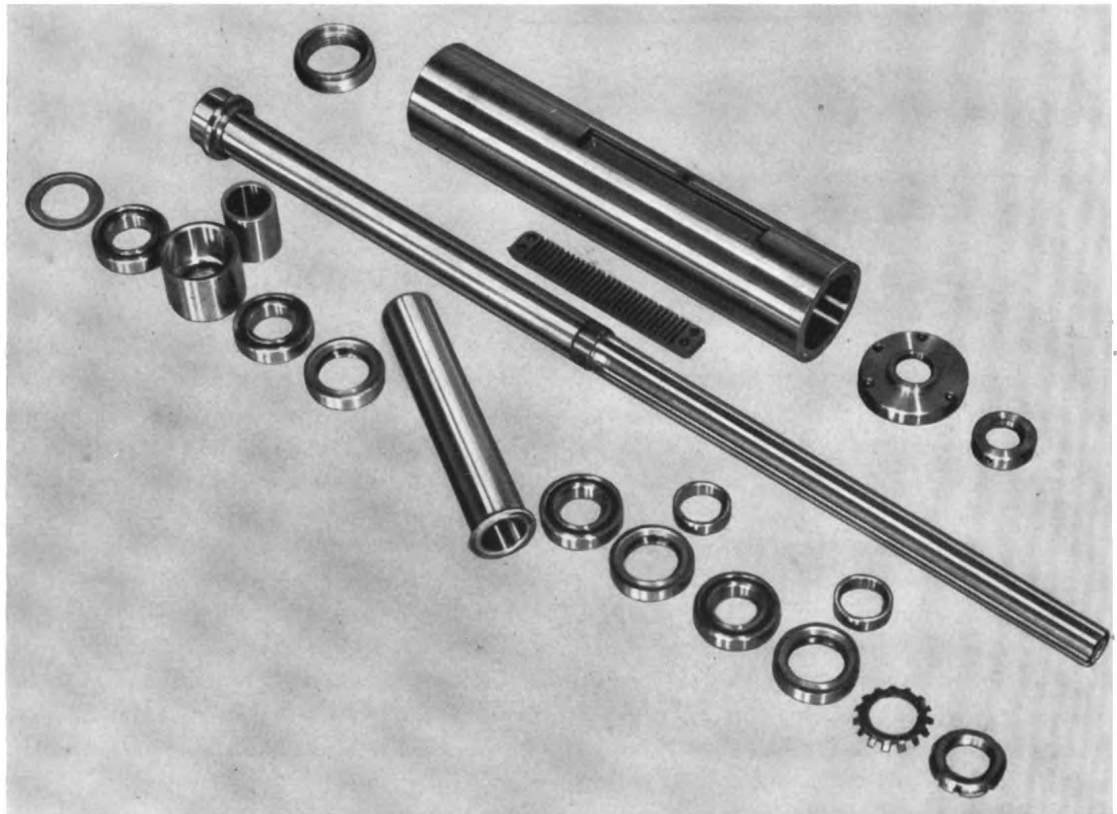


Fig. 44 — The tool end of the  $1\frac{3}{8}$ " diameter spindle is heat-treated for maximum hardness, the remainder is selectively treated for maximum strength. It is pre-lubricated and sealed for bearing life.

## ENGINEERED LOCATION EQUIPMENT STANDARDS

**Displacement by Clamping** — Clamping, or locking, of positioning members to prevent movement during the machining cycle can easily defeat its own purpose if the action, in itself, induces movement after a setting has been made. In order to guard against this not uncommon cause of error, all necessary clamping devices on Moore machines are completely non-influencing. Typical of this precaution is the method employed in locking the table, Fig. 43.

**Deflection** — Deflection under pressure of tool thrust can result in actual displacement of the axis of the hole from that of the machine spindle. While this can be minimized by using great care to take light cuts during operation of the machine, the practice reduces efficiency and does not compensate for inadequacy of design. The essential design consideration here is careful distribution of mass as a means of attaining rigidity, after a thorough analysis of possible forces to be resisted. This is not difficult to achieve in members which do not move during machine operation.

Moving parts, however, require special consideration. The spindle, being aligned in preloaded ball bearings, is not only free of any radial looseness, but is so rigidly supported as to resist deflection even under abnormally heavy operating pressure, Fig. 44.

Bending, or deflection, of the quill is avoided by use of a large cylindrical section in this member and reducing to an absolute minimum that portion extending from its supporting housing. Were this housing not movable vertically, but permanently attached to the column, the entire vertical range of the machine would have to be incorporated in the travel of the quill. This alternative is particularly undesirable because it necessitates abnormal quill projection in all but the highest working position; this factor, in itself, is adequate justification for a positionable housing.

**Thermal Expansion** — All commonly encountered engineering materials grow or shrink when subjected to temperature changes.

Examination of the following table shows that a wide differential exists between different materials.

Aluminum	12.3	} Linear expansion in <i>millionths</i> of an inch, per inch of length, per degree F.
Bronze	9.9	
Steel	6.2	
Cast Iron	6.0	
Tungsten carbide	3.3	
Invar	1.5	

These values appear minute in print, yet represent one of the most common and significant sources of error in precision measurement. The importance of this physical law can be appreciated in considering that a steel gage 10" long will expand more than half a thousandth of an inch as a result of a 10° F. temperature rise! Surely this change cannot be considered negligible in precision measurement.

The importance of thermal expansion as a source of dimensional error is greatly exaggerated by common misconceptions concerning its occurrence and behavior. While almost everyone who works to close dimensional tolerances is aware that temperature changes induce dimensional changes, the true relationship under various conditions often remains obscure.

Measurement always involves two members, the workpiece and the standard or measuring element. Should these members be of dissimilar materials, the correct dimensional relationship between them cannot be retained at any temperature other than 68° F. (standard gage temperature).

Reference to the preceding table will show that two 10-inch gage blocks, one of steel, the other of carbide, will disagree by six "tenths" at 88° F. However, should both be of either material, they will agree at any temperature, Fig. 45.

Certain qualifications must be clearly established before this example is interpreted too literally. Temperature in each case is actually that of the material, and not necessarily the room temperature. This stipulation must be recognized because, as will be later proved, difference in mass and exposed sur-

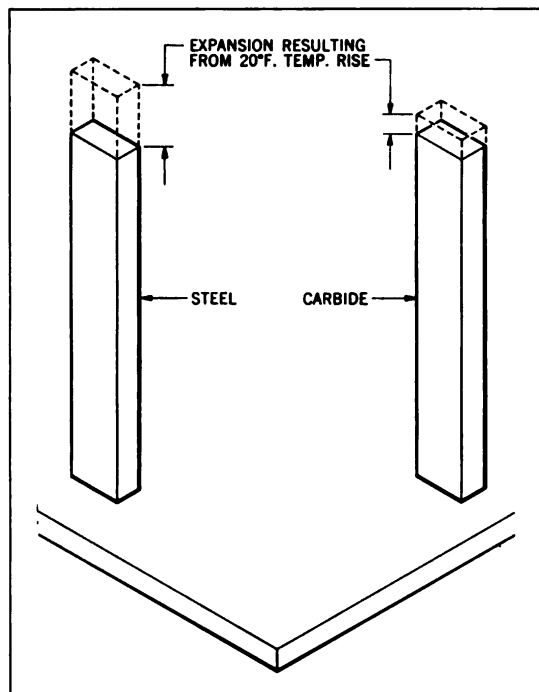


Fig. 45 — Dissimilar thermal expansion characteristics of certain common gage materials result in dimensional disagreement at temperatures other than 68° F.

face area between members prevents uniform effect from variations in room temperature. In the case of gradually changing room temperature, smaller mass and greater exposure will cause but a slight lag between part and room temperatures. Where greater mass or less exposure is involved, the lag will be pronounced.

In the use of precision locating equipment, thermal expansion is capable of causing troublesome dimensional changes in both the workpiece and the machine. This potential reduction of accuracy is neither insignificant nor inevitable. Indeed, it should be viewed as a challenge to the machine designer. A satisfactory design solution would relieve the machine user from the necessity of continually making allowances and corrections for temperature change, or of putting up with substantially less than the full accuracy of the machine.

Success in coping with thermal expansion was possible, in the opinion of Moore engi-

neers, and offered such obvious advantages as to justify an all-out attempt to overcome this final threat to operational accuracy. The complexity of varying conditions and results of thermal expansion precluded any "cure-all" solution, but rather dictated a step-by-step attempt. The first approach sought to eliminate temperature variation at its source, where possible. These sources are as follows:

1. Heat generated within the machine during operation.
2. Variations in room temperature.
3. Heat developed by stock removal.

The most serious source of temperature change during machine operation is its power plant, whether hydraulic or electrical. Since hydraulic power is the greater offender in this respect, its use in Moore machines was considered unsuitable.

Electric motors are normally rated at a 50° C. rise during operation, undesirably high for use in an accurate machine. Turning to the motor manufacturers for help resulted in the development of a motor capable of the required power output, but with no more than a 10° C. rise. Consolidating this important gain by adequate ventilation and

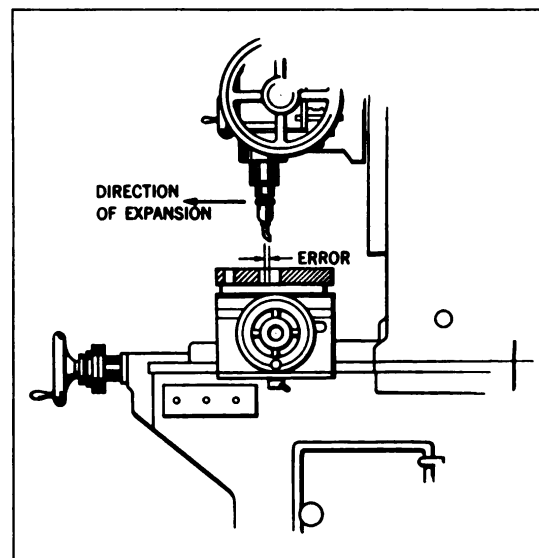


Fig. 46 — Without effective design precautions, spindle warm-up is capable of introducing significant locational errors.

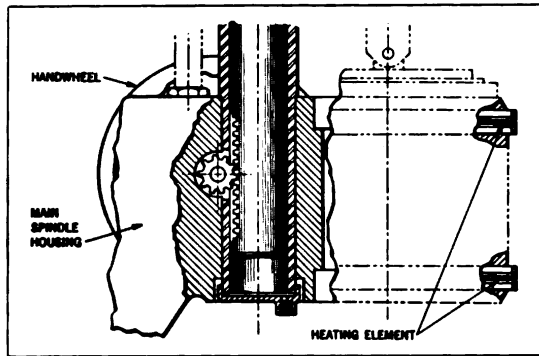


Fig. 47 — Electric resistance heaters duplicate heat output of spindle bearings while drive motor is stopped.

isolation from adjacent machine members so reduced heat transfer that the motor exerts no thermal effect on the accuracy of the machine.

Other electrical heat sources such as lights, transformers and resistance units are similarly treated so that the remaining heat developed during operation is in the so-called anti-friction bearings of the spindle.

Complete elimination of the causes of temperature variation, i.e., mechanical friction, atmospheric variation and heat of stock removal, could not be achieved solely by design. Therefore, the second phase of the campaign against thermal expansion was an attempt to neutralize the *effect* of such variations as could not be eliminated.

The relatively slight amount of heat developed by the spindle bearings produces approximately an 8° F. rise in the housing supporting it from the face of the column. Were this member cast from ordinary gray iron, a gradual shift of the spindle axis to the extent of .0004" would occur during the several-hour warm-up period of operation, Fig. 46. The danger of such an unstable reference or datum for the otherwise accurate measuring system is obvious.

Rather than impose a required warm-up period before accurate work could be done, advantage was taken of the extremely low thermal expansion characteristics of Invar, a 36% nickel iron, as a material for the spindle supporting housing. As a result of the use of this material, shift of the spindle axis was

reduced to considerably less than a "tenth" under all operating conditions.

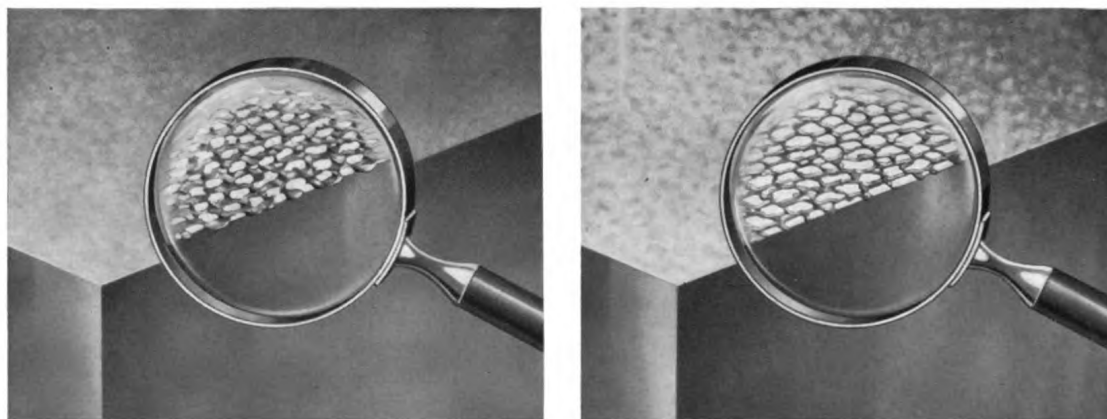
While this solution proved to be completely satisfactory for the Jig Borer, additional measures were necessary for the Jig Grinder. This can be explained by the longer time required for finishing by grinding as compared with boring and the necessary constructional differences in the spindles of the two machines.

In addition to the use of Invar in the Jig Grinder spindle housing, electric heating elements are employed to produce exactly the same B.T.U. heat output in location as that resulting from the bearings during machine operation, Fig. 47. By automatically cycling these elements in opposition to the spindle motor, a uniform temperature is maintained in this critical member, whether the machine is running or not. As a result, there is no discernible movement of spindle axis during down-time; locations established during the day's operation can be repeated the following morning.

Because temperature variation equally affecting all members of the same thermal index does not endanger accuracy, symmetrical distribution of mass is important in minimizing the effect. It is particularly desirable to enclose such critical elements as the measuring system within the machine structure. In this way dimensional changes resulting from room temperature variation are proportional throughout the machine, and operational accuracy is more nearly independent of room temperature.

In view of its more obvious advantages, the lead screw measuring system is seldom recognized as an important factor in contending with thermal expansion — by virtue of its rapidity of setting. This provides the operator with a strong incentive to follow the best practice of roughing all holes before finishing any of them. In this way the heat of stock removal and room temperature variations have the least possible time in which to affect the workpiece.

Thus, in design, it has been possible to project static accuracy of location, or measure-



*Fig. 48—Rubbing mating surfaces together increases the area of individual bearing points, and thus the total effective plane. This practice minimizes the initial rate of wear of scraped surfaces in the same way that lapping does for ground surfaces.*

ment, into dynamic accuracy of operation. The accuracy of location in machining is now equal to that which can be achieved in inspection.

**Permanence of Accuracy**—Second only in importance to high initial accuracy in precision locating equipment is the life expectancy of this accuracy. The achievement of operational accuracy should not be considered the ultimate until its repetitive permanence is assured. Probably no source of error is more troublesome than that which might gradually develop *after* a machine has established its reputation for performance accuracy!

Wear constitutes the obvious threat to long-lived accuracy of precise locating equipment. By definition wear is removal of material from a surface by abrading, as a result of use. Much can be done to reduce both the *rate* and the *effect* of wear. Surely the value set upon accuracy, by the pains taken to attain it, justifies an equal effort to retain it.

Rate of wear is governed by several factors:

1. Wear-resistance of the material.
2. Amount of *actual* contacting surface area in relation to the load supported.
3. Lubrication.
4. Presence of abrasive foreign matter.
5. Refinement of surface finish.

In Moore machines each of the above factors is treated in accordance with the best practice.

Castings are of a hardness just permitting hand scraping but offering great resistance to wear. Their way surfaces, after hand scraping, are rubbed together with their mating members to level off the inevitable high points to plateaus constituting approximately a 60% bearing area, Fig. 48. With adequate lubrication and protection against intrusion of abrasive foreign matter, the resultant surface will retain its accuracy of plane for many years.

Functional steel parts, such as the quill, are of close-to-carbide hardness. After grinding, they are lapped to a high surface finish. Such parts, accurately fitted to each other, show no measurable wear over a period of at least ten years. The effect of wear, inevitable though it ultimately may be, is minimized by the same close-coupled design relationship between ways and workpiece discussed in connection with closeness of fit in moving parts. As a matter of fact, wear results in much the same conditions encountered with initially loose fits.

The use of long bearing surfaces, particularly for sliding movement, and the non-influencing clamps highlight the wear-inhibiting features which have proved effective in these machines.

Far less obvious as a threat to prolonged accuracy is the seldom-recognized type of dimensional instability having its origin in the complex micro-structure of hardened steel.

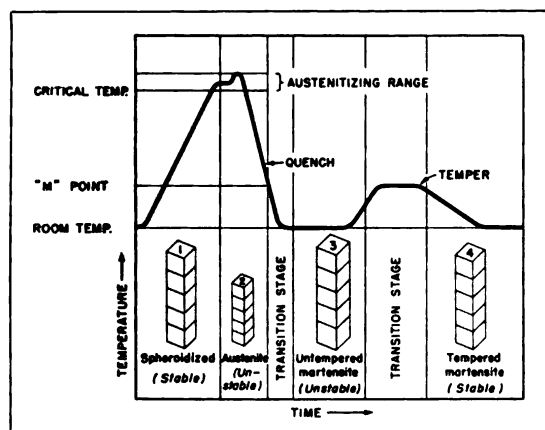


Fig. 49 — Volume changes occur in steel during transformation of structure. The cubes graphically represent these changes during a hardening cycle. Only structures 1 and 4 are equal in size and stable.

Although this permanent form of instability should concern anyone making or using accurate measuring equipment, it is seldom correctly identified as the cause of otherwise inexplicable dimensional variations. While this peculiar behavior of steel is explained in the advanced texts on physical metallurgy, little has been done to present information relating this phenomenon to other engineering considerations in the field of metrology. In an attempt to fill this gap the following discussion of permanent instability will be allotted more space than would otherwise be necessary.

Hardened steel, in addition to its well-ordered obedience to the laws of thermal expansion, is subject to erratic and entirely unrelated dimensional variations of considerable magnitude. These changes can be either shrinkage or growth and may occur under the following conditions:

1. A slow progressive change, continuing for months or years, which may start immediately after hardening or at any time thereafter.
2. An instantaneous and completed change at any time after hardening.
3. A reversal of the direction of change at any time after hardening.

In view of the absence of any observable pattern, it is little wonder that dimensional changes of this nature are usually dismissed

as errors of observation, or the result of being "tenth-happy."

The root of the whole problem lies in the fact that hardened steel is very seldom a homogeneous structure, but is composed of at least two constituents in varying proportions. Being unstable at room temperature, these constituents are prone to decompose with a resulting volume change and a change in the dimensions of the steel.

As a simple illustration, a combination of oxygen and hydrogen in the proportions  $H_2O$ , or water, occupies a volume, between boiling and freezing, that is governed entirely by its thermal coefficient of expansion. Upon freezing, however, it suddenly expands in volume, in apparent disregard of the laws of thermal expansion. Water, completely free of any dust particles, will remain liquid, still obeying the laws of thermal expansion, when cooled far below its normal freezing point of  $32^\circ F$ . However, it is unstable at this low temperature, and a slight vibration or dust particle will cause it to freeze solid instantly, with the accompanying change in volume. It will be demonstrated that this analogy bears great similarity to the conditions causing instability in hardened steel.

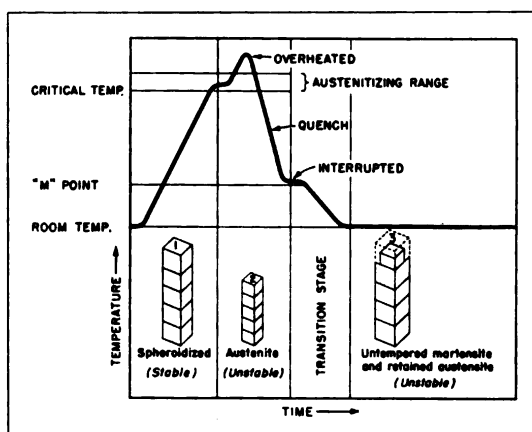


Fig. 50 — Overheating, interrupted quenching and the presence of alloying elements produce unstable constituents in hardened steel. If retained austenite converts to untempered martensite (dotted outline), growth will occur. Under certain conditions it will also promote conversion to structure 4 (Fig. 49) with attendant shrinkage.



Courtesy of General Electric Co.

Fig. 51 — A Metals Comparator permits non-destructive testing of hardened steel for potential instability.

During the hardening cycle, steel responds to the laws of thermal expansion as it is heated to the so-called critical temperature. At this point the steel undergoes a marked change in crystalline structure; in its new form it is called austenite. This transformation is marked by a sudden *decrease* in volume, in defiance of the laws of thermal expansion. To restate this: Austenite is less voluminous than

the structure from which it was formed, Fig. 49.

Cooled rapidly enough, this austenitic structure is carried down to about 400° F. At this point the austenite becomes so unstable that it begins to transform to a new structure called martensite, the familiar, hardened form of steel. This reaction is marked by a sudden increase in volume, and continues down to

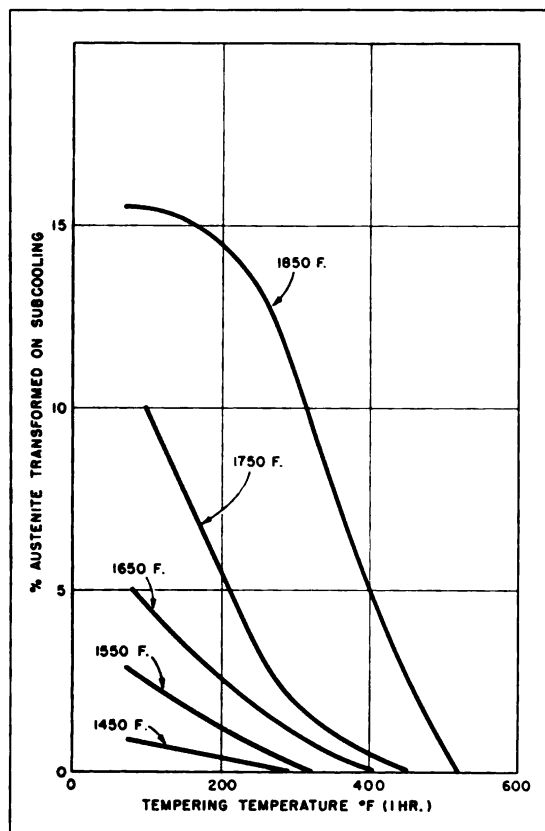


Fig. 52— These curves show the conversion of retained austenite by sub-cooling. By selecting suitable austenitizing and tempering temperatures, no austenite will be retained. The latter also stabilizes the untempered martensite which is not affected by sub-cooling.

room temperature. Due to the presence of alloying elements and a certain sluggishness of the austenite, the reaction is almost never complete, with up to 30% austenite retained, Fig. 50.

This retained austenite, existing unnaturally at room temperature, gradually decomposes, or if subject to thermal shock may transform very rapidly. In either case, a volume increase or growth results, the magnitude depending upon what percentage of the austenite was transformed. Conversion of but 1% of the steel's volume will result in a growth of approximately .0001" per inch of section.

Freshly formed martensite is also unstable, tending to decompose into a secondary form which, although stable, occupies slightly less

volume. This transformation is generally completed in a relatively short time.

Thus it is apparent that, singly or in combination, these unstable constituents are capable of introducing dimensional errors which may largely cancel the accuracy painstakingly worked into any part so affected. The following case histories will illustrate the gravity of this source of error:

#### CASE A

*Specimen:* An 11-inch gage block of tool steel, presumably correctly hardened and tempered by a commercial heat-treater.

*Conditions:* Finished accurately to size by grinding and lapping and kept at room temperature for six months.

*Observation:* At the end of the six months a growth of .0135" was noted, and upon examination the steel was found to contain 10% retained austenite.

*Conclusion:* Unsuspected variations in heat-treatment must have led to the retention of about 22% austenite, since the decomposition of 12% would account for the dimensional change as noted.

#### CASE B

*Specimen:* A high quality four-inch gage block from a commercial set guaranteed to a tolerance of .000002".

*Conditions:* Used for a year in a temperature-controlled room as a master block for reference.

*Observation:* At the end of a year comparison showed a suspected growth of .00004", later verified by the National Bureau of Standards. The manufacturer later replaced this block on a no-charge basis.

*Conclusion:* Whether this growth resulted from decomposition of a very small part of a large percentage of retained austenite or the complete conversion of a small percentage retained could not be determined since the test would be destructive. No doubt, however, existed as to the cause of the trouble.

It can be seen from these examples that only eternal vigilance can be relied upon to

# HOLES, CONTOURS AND SURFACES



Fig. 53 — Suitable accessories eliminate the need for improvisation and its attendant danger of inaccuracy.

## ENGINEERED LOCATION EQUIPMENT STANDARDS

detect such inaccuracies. They generally develop so gradually as to be virtually undetectable for some time. During this period a great deal of damage may be done in perpetuating the error.

Potential instability can be detected in steel by several methods, the most accurate being X-ray diffraction examination, which reveals the exact percentage of retained austenite. But this can only be considered as a post-mortem type of test. Generally the result is destructive to the workpiece, and few laboratories have the necessary equipment.

Since austenite exhibits a difference in magnetic permeability, as compared with martensite, it is possible to non-destructively examine a specimen in comparison with a known sample by a commercial instrument, Fig. 51.

As a result of metallurgical research in one of our leading technical institutes, stabilizing cycles have been developed that effectively eliminate this threat to accuracy, Fig. 52. Utilization of this technique and verification of its effectiveness by suitable inspection as-

sure the permanence of the accuracy built into each Moore machine.

### COMPLETE LOCATING SERVICE

It is true that equipment specifically engineered for the purpose provides the biggest contribution to the accuracy and efficiency with which holes, contours and surfaces can be located. But it alone cannot do the job. Suitable accessories and sound operating practices are necessary in order that the machine may fulfill its intended purpose.

It is toward this objective that the theme of "a complete locating service," stressed in this book and by Moore, is directed. This service includes accessories which are integrated with the design and function of the machine, Fig. 53, and instructions to guide the operator toward the most effective practices. Only in this way can the danger of loss of accuracy through makeshift tools or methods be effectively eliminated.

In the following chapters the Jig Borer, Jig Grinder and Form Grinder will be successively discussed in relation to principles and practices applicable to each.



*The Coordinate Locating System.*



## THE COORDINATE LOCATING SYSTEM

THE COORDINATE locating system is a method of positioning work by rectilinear movement of the Jig Borer or Jig Grinder table, controlled by a measuring system based on the relationship of the flat plane, the square and linear measurement described in Chapter 3. It is equally a system of dimensioning the workpiece on the drawing boards. In clarification of this point a case will be cited which should serve to illustrate how essentially simple and adaptable this system is. The derivation of the dimensions on the drawing will first be established, and this, in turn, related to the measuring system of the machine.

The basis of the rectangular coordinate system lies in the dimensioning of all points from crossed ordinates, or zero lines, external to the workpiece. These will be shown as scales along the upper and left-hand edges of a piece of drawing paper. In Fig. 54, the workpiece is shown drawn into the intersection of these scales, its edges aligned with 0 in both directions. In this presentation, the location of the holes in relation to the scales and to the conventionally dimensioned drawing of the same piece, shown in Fig. 55, is clearly revealed.

Re-drawing the same piece more nearly central on the paper, Fig. 56, in no way alters the relationship of the holes to each other and to the edges, even though the latter no longer are aligned with the zero ordinates. From this example it may be seen that the relationship of the zero ordinates to the workpiece is

a matter of choice and can be altered to suit requirements.

The advantage of having the zero lines external to the workpiece becomes more apparent in the case of a workpiece picked up from an existing hole or dowel, Fig. 57. Should the pickup point be considered zero, it is apparent that any locations to the left or above this point would be indicated by a confusing negative value, incompatible with any measuring system.

Fig. 58 represents the same piece as shown in Fig. 55 with the dimensions re-written in the form of a conventional Jig Borer layout for operator convenience. An alternative, though not so effective, presentation is shown in Fig. 59.

While the ideal arrangement would call for all drawings to be presented to the operator in the form of approved Jig Borer layouts, this is seldom given sufficient consideration. Several points favor this arrangement:

1. Once introduced, the rectangular coordinate system of dimensioning is often as convenient in original design as the more conventional form.
2. Drawings which have been conventionally dimensional usually require a certain amount of calculation in conversion to coordinates. This may necessitate a knowledge of trigonometry and mathematical ability beyond that which might be expected from an operator. This operation can, therefore, be performed more efficiently and safely in an engineering office than in the shop. Where more than an

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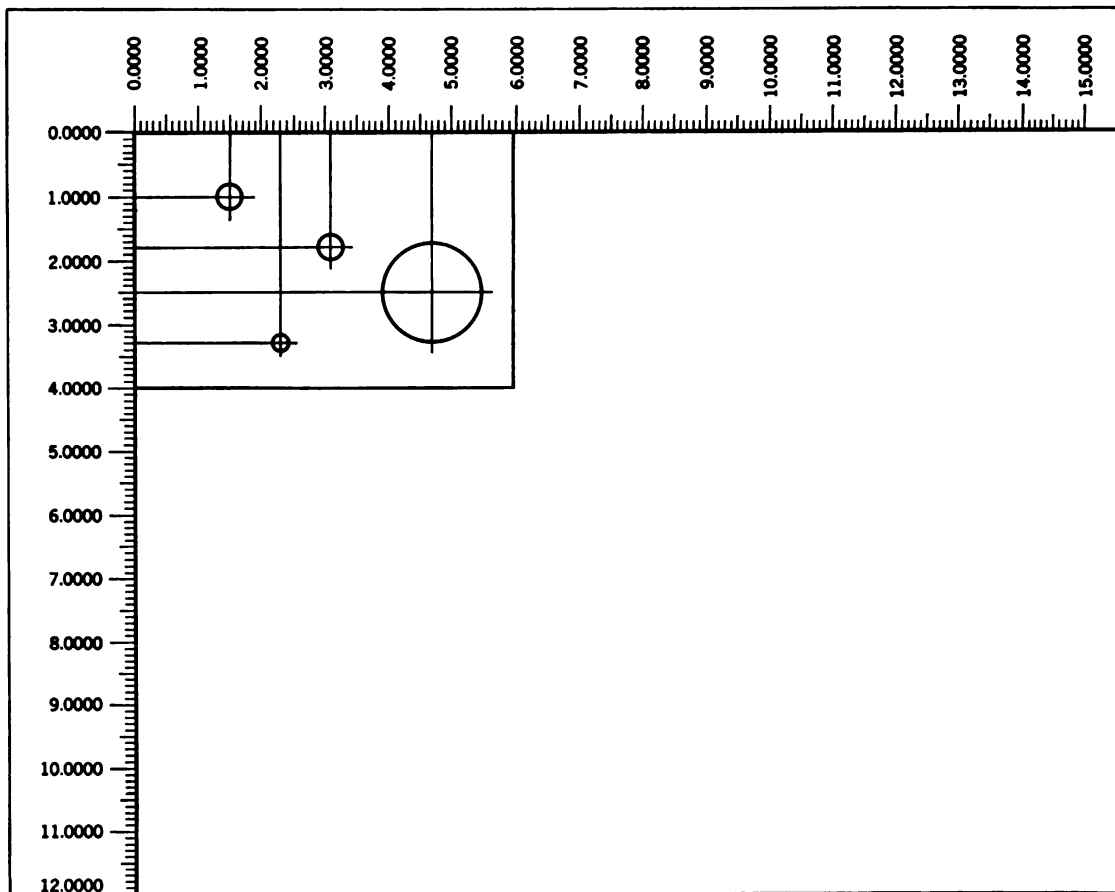


Fig. 54 — Graphic representation of workpiece, crossed ordinates and graduated scales. In dimensioning, this relationship is based on imaginary scales and zero lines. In machining, the scales are represented by the lead screws and the intersection of the zero lines by the spindle axis.

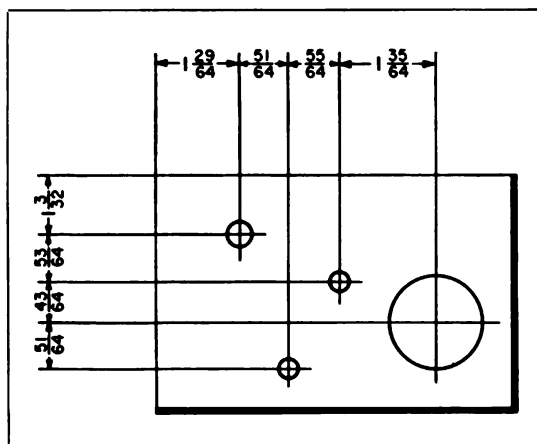


Fig. 55 — The cumulative nature of conventional dimensioning is more haphazard than coordinate dimensioning.

occasional job of this sort is done, a calculating machine capable of extracting square root will justify its cost.

3. Calculations made by the operator not only use up his time, but keep the machine standing idle.

In order to relate our example of coordinate layout to the measuring system of the machine, it will be necessary to refer briefly to that portion of Chapter 7 which describes the dimensional pickup of the workpiece, i.e., relating its reference point to the measuring system and spindle axis.

Having set up the work and zeroed one edge in line with the spindle, the zero bracket on the scale is set to the nearest full inch and the corresponding dial set to zero. Proce-

## THE COORDINATE LOCATING SYSTEM

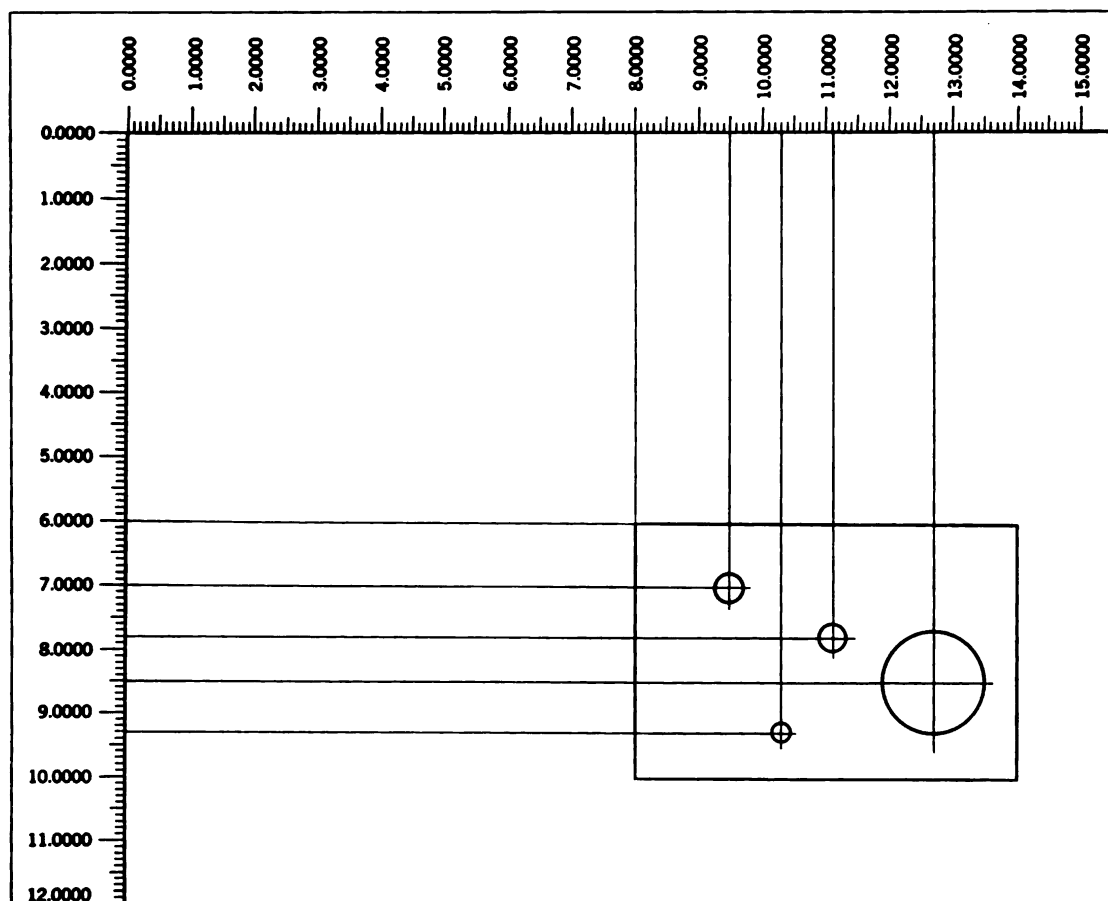


Fig. 56 — Re-location of the workpiece within the coordinate system does not alter its dimensional values.

ture is identical in relation to the other edge. On completion of this step it may be necessary to alter the figures on the layout to agree with the new settings of the scales and dials. Reference to Fig. 56 will show that when new values are established during pickup, correction of the locational values presents no problem. It requires only the adjustment by whatever numerical difference exists between the pickup and the layout reference. Fig. 60 illustrates the relation of work to machine.

Should the starting point be an existing hole or dowel, it is not necessary to start from an even inch; the scales and dials may be set to the values indicated on the drawing. In this case also, it may be necessary to correct for the inch values.

**Polar Coordinates** — This is the conventional dimensioning system employed to designate

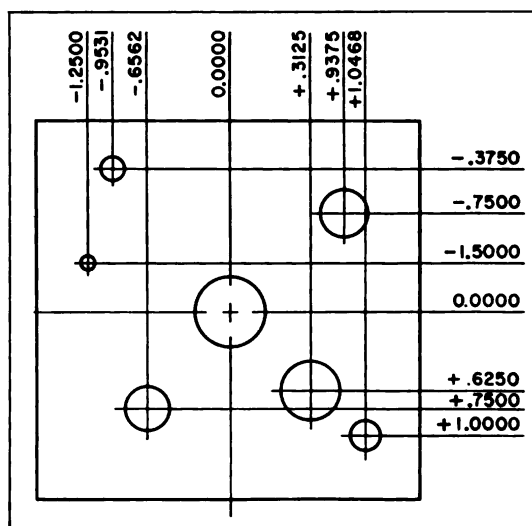


Fig. 57 — Inability to shift the relation of the pickup point of the work to the coordinate system would result in confusing negative values, as illustrated in this example.

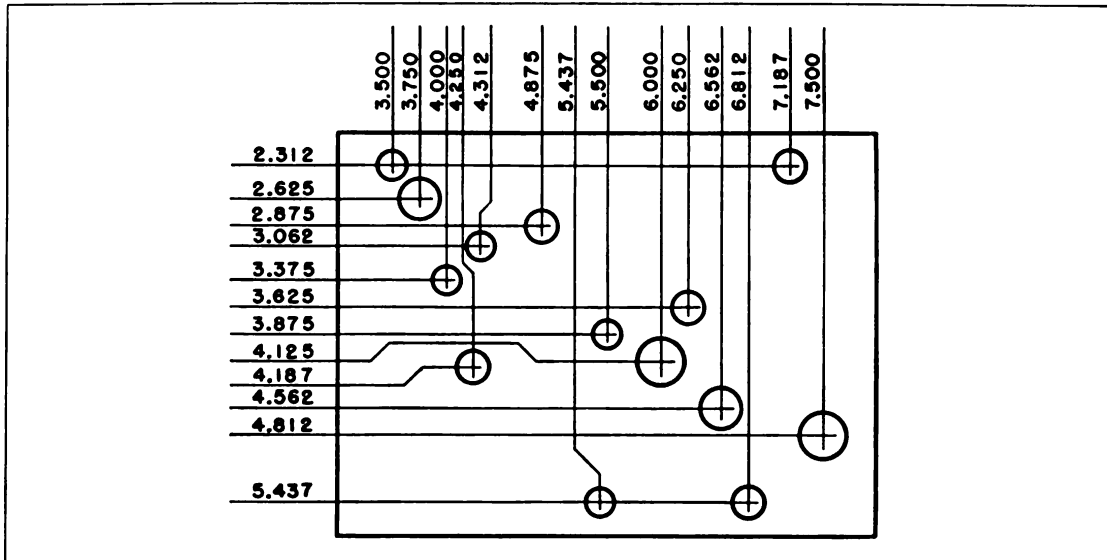


Fig. 58 — A preferred form of coordinate dimensioning.

the location of holes in a circle, equidistant from a common point, Fig. 61. Such dimensioning takes the form of an angular value between holes and their radius from a common center. In establishing the angle for each hole it is necessary to divide the number of holes into  $360^\circ$  in order to determine the spacing angle which must be successively added for each hole. Should the number be

unevenly divisible into  $360^\circ$ , care must be used in the calculation, since even a small numerical error will result in a sizable cumulative error.

Once derived, polar coordinates lend themselves directly to use with the rotary table for machining setup, Fig. 62. By displacing the center of rotation from the spindle axis to the amount of radius given, each hole can be

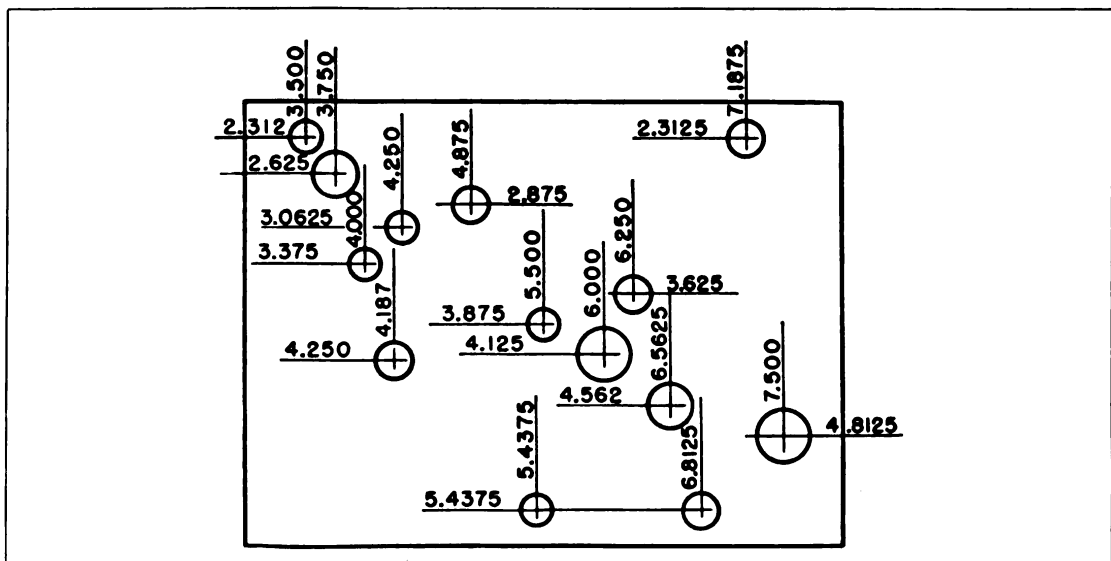


Fig. 59 — An alternative form of coordinate dimensioning.

# THE COORDINATE LOCATING SYSTEM

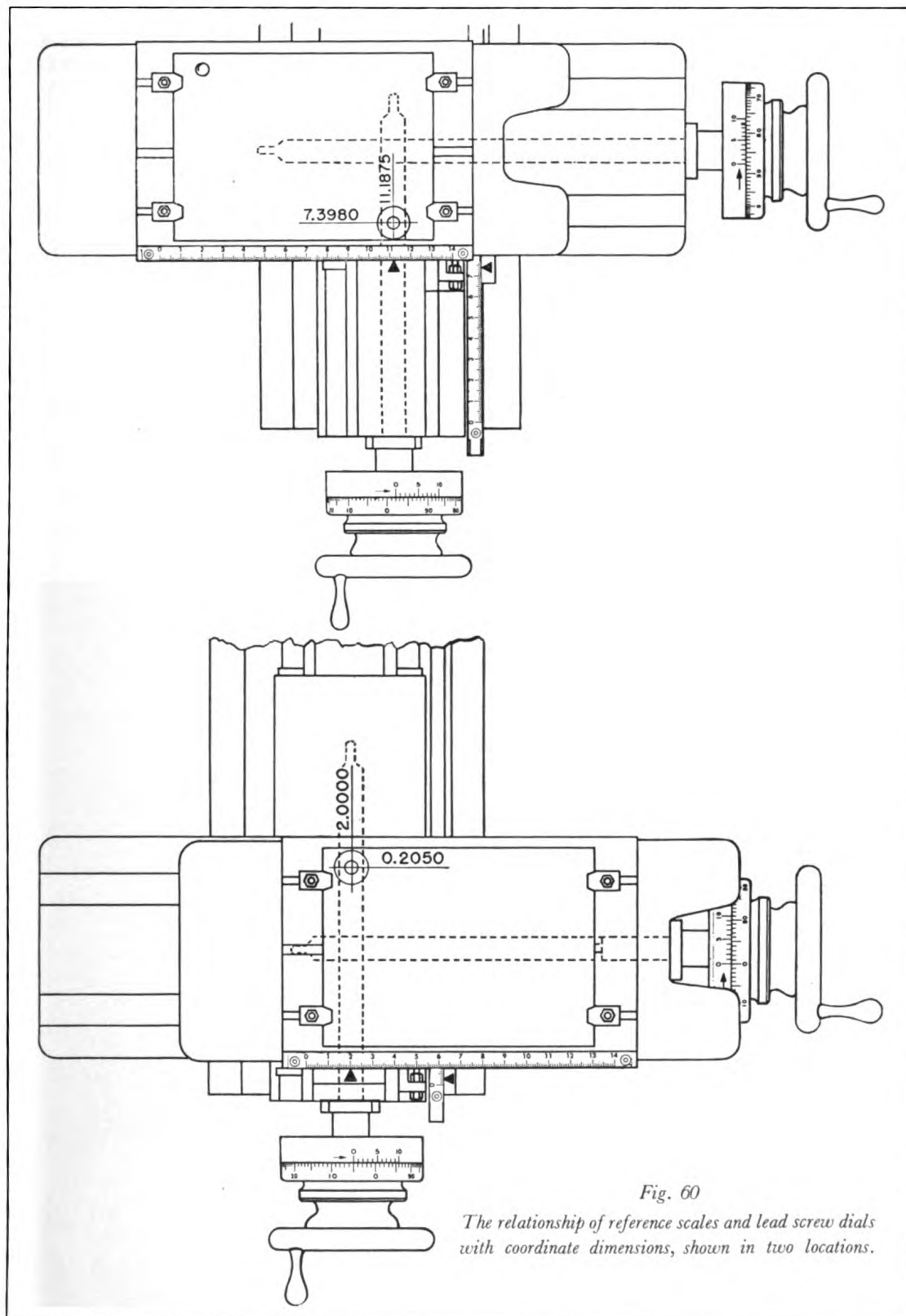


Fig. 60

The relationship of reference scales and lead screw dials with coordinate dimensions, shown in two locations.

## HOLES, CONTOURS AND SURFACES

located successively by angular setting of the rotary table.

In order to facilitate the calculation of polar coordinates, the Woodworth Tables (page 225) give the angle between holes for any number of evenly spaced holes up to 100.

Unless a highly accurate rotary table is used, such as the one shown in Fig. 62, errors of considerable magnitude may result from this form of positioning. As a result, it is often desirable, for the highest accuracy, to convert polar to rectangular coordinates and use the measuring system of the machine for spacing. The strongest deterrent to this practice lies in the lengthy calculations necessary. In order to simplify this, the Woodworth Tables also

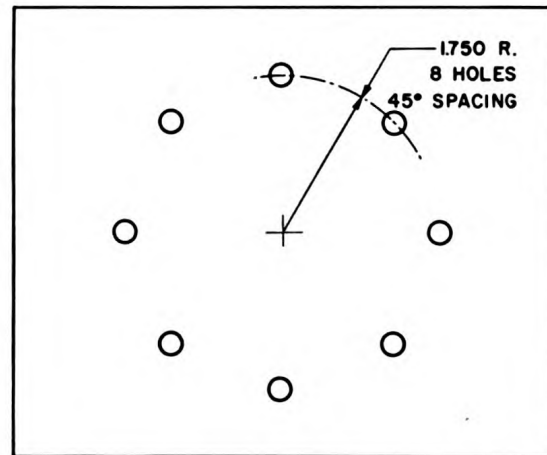


Fig. 61 — Polar coordinate dimensioning of a circle of holes.

Fig. 62 — The use of a rotary table as a convenient means for equally spacing a circle of holes. The No. 2 Moore Rotary Table is of the non-disengageable worm type and will retain its high initial accuracy indefinitely. Available with index plates in either a storage box or a special casted desk-type stand, this accessory is conveniently used with either the Jig Borer or the Jig Grinder.



## THE COORDINATE LOCATING SYSTEM

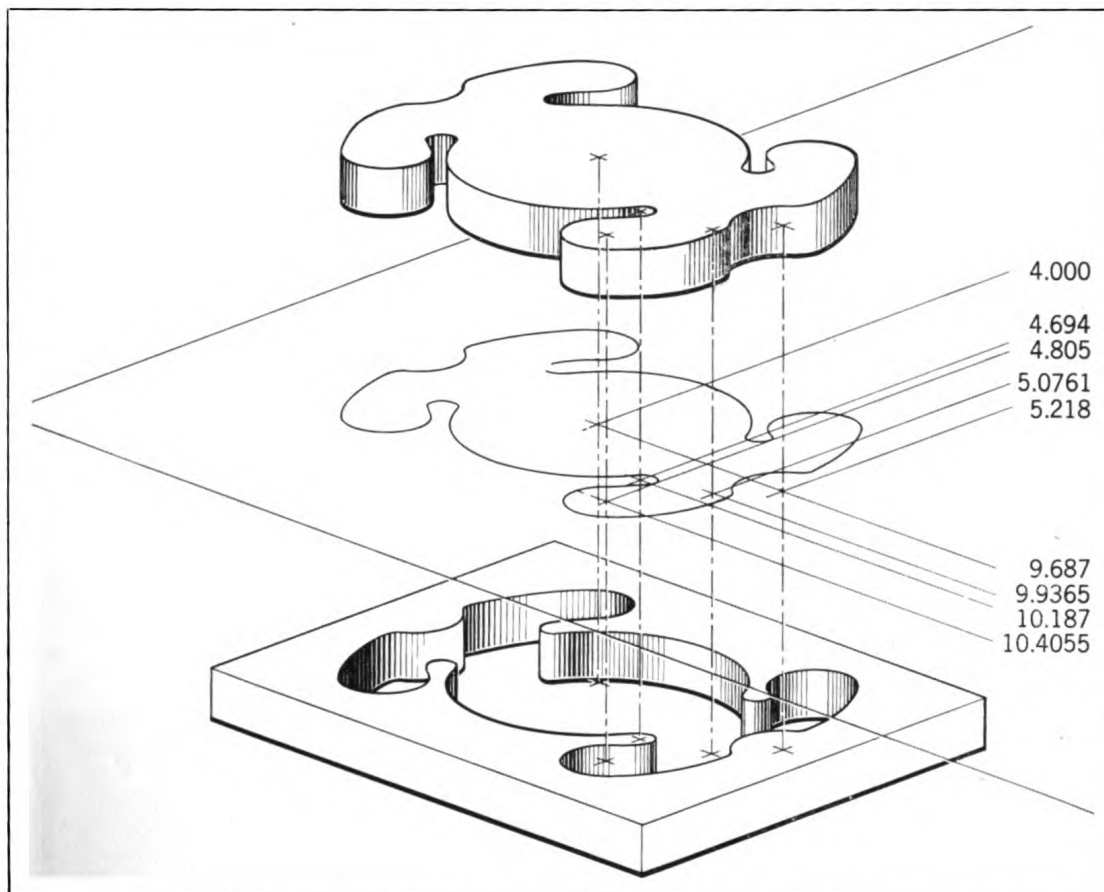


Fig. 63 — Coordinate layout of punch and die from the stator-rotor lamination die.

give factors for direct conversion, up to 100 holes in a circle.

Controversy over the relative merits of the polar vs. rectangular coordinate system in practice cannot be resolved without consideration of all the factors pertaining to any specific job. There are certain general points, however, which can be cited in reference to work done on a rotary table.

Most important are:

1. Picking up the center of the rotary table in relation to the machine spindle provides a source of error.
2. Relating the workpiece to both the axis of the rotary table and the spindle introduces another chance for error.
3. Errors in the angular measuring element of the rotary table must be taken into account.
4. Any shift in the location of the spindle axis,

such as would result from temperature change, is a potential source of locational inaccuracy.

The errors from the above sources may be *doubled* in the work, as a result of rotation of the table, in much the same way that eccentricity of a revolving member is shown as a double value on an indicator. In addition, any errors of the rectilinear positioning system must be included, since the distance from the center must be measured by it. The evidence adds up to the fact that no matter how accurate the rotary table, higher accuracy can generally be attained by use of the rectangular coordinate system of location. Contours, represented by the punch and the die section of the stator-rotor lamination die, are most effectively dimensioned by rectangular coordinates. In this example, Fig. 63, both the punch and the die are made to the same layout.



*Fig Boring Principles and Applications.*



## JIG BORING PRINCIPLES AND APPLICATIONS

THE SIGNIFICANT features of the Jig Borer lie in its directness and rapidity in attaining the highest order of locational accuracy. These attributes, together with its versatility and efficient stock removal, explain its rapidly increasing acceptance in widely varied phases of the mechanical industries, from toolroom to production line, from experimental laboratory to inspection department.

It is a natural consequence that such diversified uses of the machine tend to place emphasis on various of its capabilities. In order to provide the broadest possible perspective for appraising the value of Jig Boring, study of specific jobs will be postponed in favor of the more revealing and generalized consideration of typical Jig Borer applications.

Since the Jig Borer was developed primarily to fill a pressing need for an adequate solution to the toolmaker's ever-present problem of precise location, its first acceptance and widest general use has been in the toolroom. Used alone or in partnership with its companion machine, the Jig Grinder, the Jig Borer has done much to promote interchangeability in toolmaking. It has also increased the toolmaker's capacity, relieving him of the tedious job of locating holes by makeshift methods.

**Toolmaking** — The wide variety of Jig Boring operations encountered in toolmaking precludes any attempt at complete or orderly classification. Only the broadest general categories can be cited.

As its name implies, one of the basic uses

of the Jig Borer is in jig making. Jigs may range from the simple plate type, requiring only an accurate dimensional relationship between bushing hole and locator, to complex box jigs incorporating numerous holes and surfaces in several planes. In the latter type the true importance of the "cubic concept of accuracy" can be appreciated, Fig. 64. The ability to project geometric accuracy through a vertical range is the key to product quality.

Even in cases where the workpiece to be produced from a jig does not require hole location to a "tenth," the bushing holes can be Jig Bored much more quickly, and to high accuracy, than they can be produced by any other means to even broad locational tolerances.

Press tools, ranging from simple dies not requiring the highest accuracy to compound and progressive dies necessitating the greatest precision, are an obvious "natural" for the Jig Borer, Fig. 65.

As a case in point, the significant accuracy contribution of the Jig Borer to the stator-rotor lamination die lies in the precise location of holes in the punch plate. Worthy of special mention are the pilot holes and the bushing holes guiding the aligning posts of the stripper, Fig. 66.

Dies not requiring high accuracy can be Jig Bored and left unground after hardening. Distortion errors in hole location can be determined by picking up the location of holes, after heat treatment, in the Jig Borer,

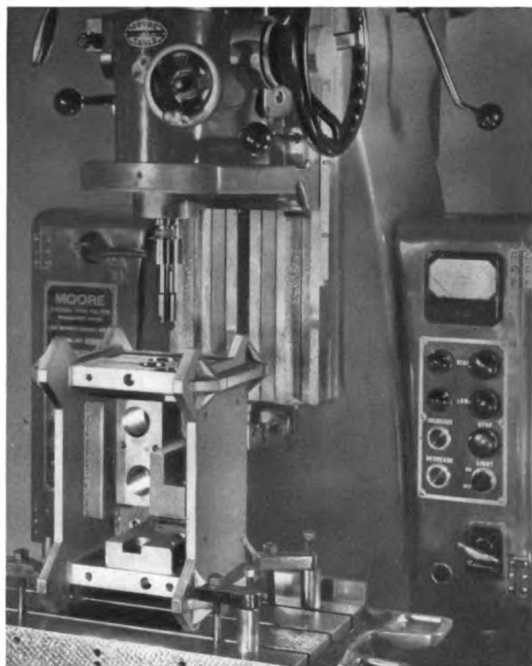


Fig. 64 — Workpieces such as this box jig, necessitating locational accuracy in several planes, prove the importance of the "Cubic Concept of Accuracy."

and establishing a new set of coordinates to which the unhardened, related members such as stripper and punch plate may then be Jig Bored.

More complex or precise dies require grinding after hardening. The ideal solution, both from the standpoint of efficiency and accuracy, is Jig Grinding. In this way, all parts can be Jig Bored to coordinate location, with all die openings left a few thousandths undersize to permit re-establishment of location by Jig Grinding after hardening. Parts not requiring heat-treatment can be bored to size.

The advantage in Jig Boring parts which will subsequently be hardened and Jig Ground is purely a matter of efficiency. It is normally desirable to leave no more stock for grinding than is necessary for economic reasons. This condition can only prevail if the original location is precise, because any tolerance at this point must be added to the allowance for anticipated distortion. The fact

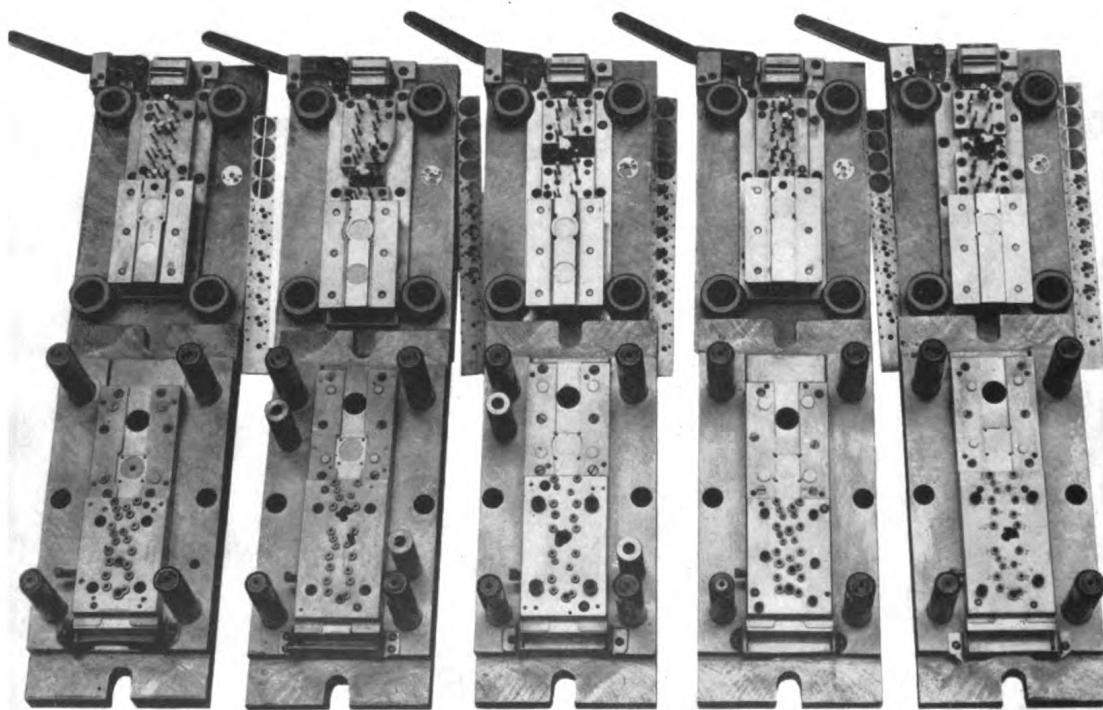


Fig. 65 — Typical Jig Borer work is represented by these progressive dies which pierce, shave, gut and blank timing device parts. Holes are precisely Jig Bored in punch plate, stripper and die shoe, insuring accuracy of alignment.

## JIG BORING PRINCIPLES AND APPLICATIONS

that the Jig Borer can locate the holes accurately and remove stock so rapidly is all to the good, since *there is no faster method within acceptable limits of accuracy*. In Jig Boring holes to be ground later, it is unnecessary to size to a "tenth," a further saving of time.

Assuming that a Jig Grinder is not available, the Jig Borer may be used to re-establish coordinate location prior to grinding in a conventional internal grinder. This is accomplished in the following sequence:

1. After the die is hardened and surface ground, soft plugs (steel or brass) are fitted to the holes to be ground.
2. The die is set up in a Jig Borer and small holes bored in the plugs to the same coordinates as were used in the original Jig Boring; this re-establishes the desired location, which could no longer be trusted after hardening, Fig. 67.
3. One at a time, these holes in the plugs are indicated true with the axis of the internal grinder, Fig. 68, the plug removed and the die opening ground to size, Fig. 69.

While this is not as accurate as Jig Grinding, and far less efficient from every standpoint, it is the most satisfactory of substitute methods.

**Model Work** — The same versatility and accuracy necessary for toolroom applications make the Jig Borer a key machine in model, experimental and development work. In this role it enables inexpensive, yet accurate, sample or prototype parts to be produced quickly; in other words, it makes the job interchangeable even before it is tooled. Such parts may be required to verify dimensional relationships, establish effective tolerances or to permit visualization of production methods and problems. In many instances whole prototype assemblies are made, relying only on the Jig Borer for dimensional accuracy.

**Production** — Although conceived as a toolroom machine, the Jig Borer can often be a production machine. The same flexibility, accuracy and impressive rate of stock removal which have made it indispensable in toolmaking make it equally adaptable to the production line. This is attested by the number of such installations in industry, one con-

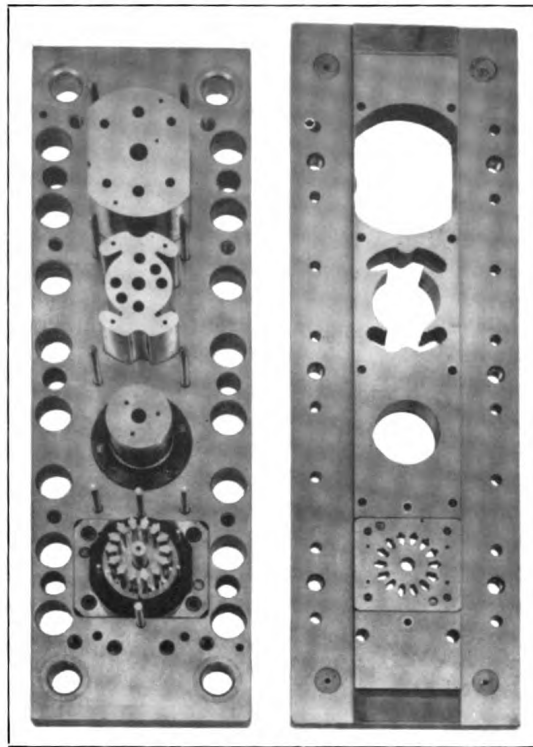


Fig. 66 — Punch plate and stripper of the stator-rotor lamination die illustrate the requirement for the locational accuracy of the Jig Borer.

sisting of a battery of fourteen Moore Jig Borers solely employed on direct production work, Fig. 70. It is being efficiently and effectively used for a wide range of applications which include:

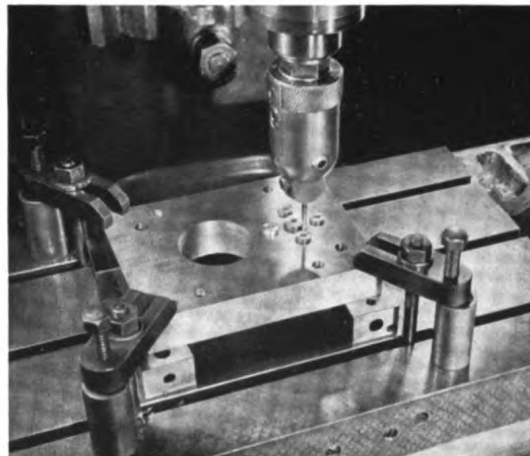
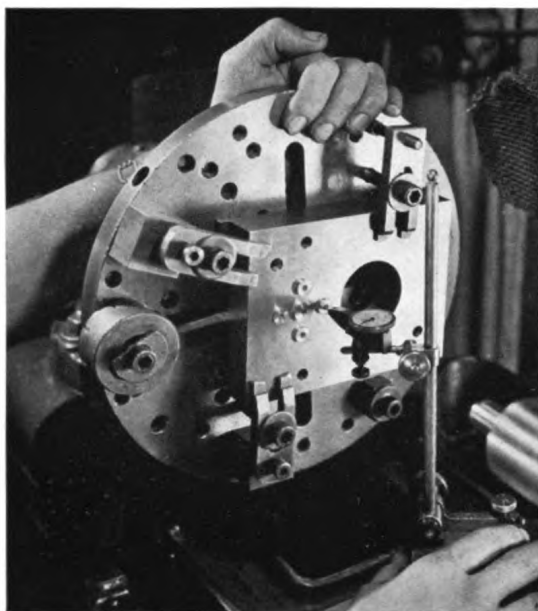
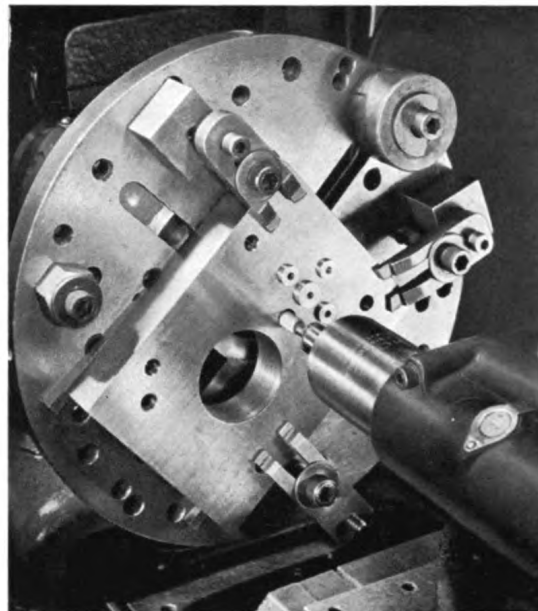


Fig. 67 — The work is reoriented after hardening and a small hole Jig Bored in each plug to re-establish location to the original coordinates.

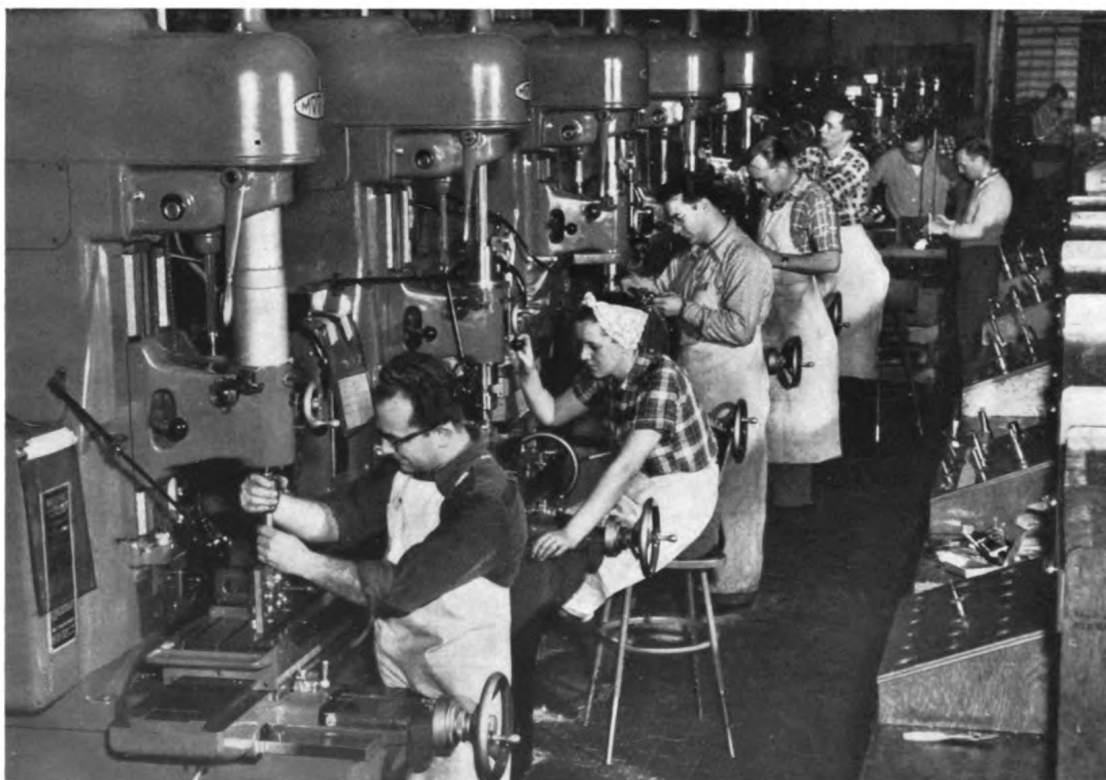
# HOLES, CONTOURS AND SURFACES



*Fig. 68 — Each hole must be carefully indicated from the spindle of an internal grinder.*



*Fig. 69 — After pickup, the plug is removed and the hole is ground in the conventional manner.*



Courtesy of American Bosch Arma Corp.

*Fig. 70 — Convenience, accuracy and efficiency are the keynotes of this battery of Moore Jig Borers employed in production work.*

## JIG BORING PRINCIPLES AND APPLICATIONS

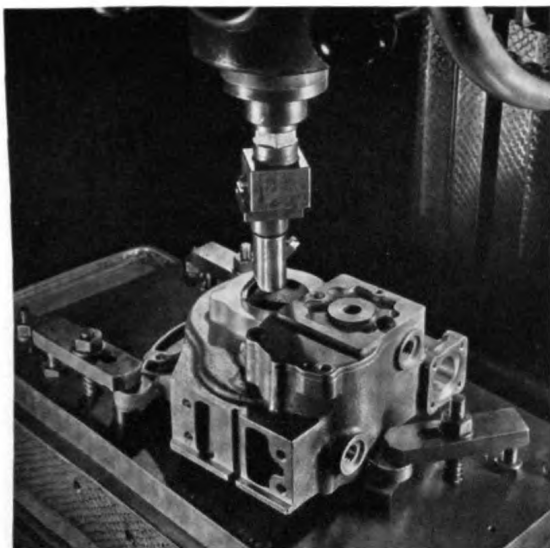


Fig. 71 — Versatility of the Moore Jig Borer makes production jobs like this a "natural."

1. Production before tooling, where parts must be produced in quantity before jigs can be completed.
2. Small-lot production where the quantity would not justify the cost of tooling.
3. Production of parts where the necessary accuracy of hole location or quality of surface finish cannot be attained in a drill jig.
4. Production of parts requiring highly accurate relationship between multiple operations which cannot be incorporated in a jig, such as boring, facing and light milling, Fig. 71.
5. Production of delicate or complex parts which must be bored to attain accuracy and avoid distortion, Fig. 72.

In all of the preceding examples, the flexibility of the Jig Borer is in direct contrast to the inflexibility and single-purpose nature of special machine tools. This permits desirable product design changes to be made without having to justify the delay and cost of re-tooling.

**Inspection** — The potential of the Jig Borer in inspection is recognized only infrequently, yet a review of its design features will show that it possesses all the necessary elements of a highly precise, universal measuring machine. Obviously, its ability to *locate* or *position* accurately, in turn, makes it possible for the Jig Borer to *measure* or *inspect* accurately.

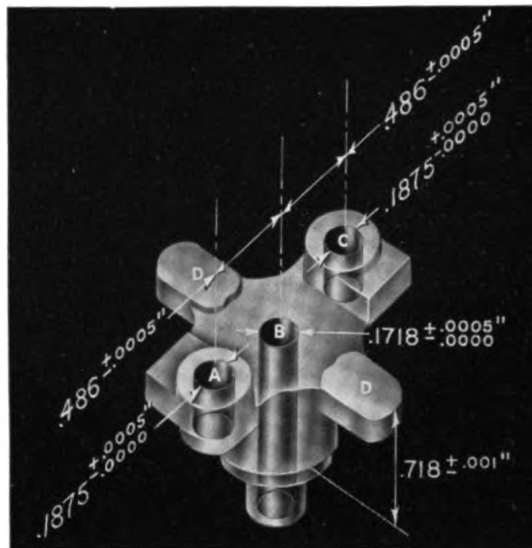


Fig. 72 — An aluminum stud production Jig Bored to close tolerances.

The use of the Jig Borer for inspection is found in:

1. Inspection of work produced on the machine itself, by the inspector.
2. Inspection of work produced elsewhere.

Work completed in the Jig Borer can be most effectively inspected before it is removed from the machine. By checking the location



Fig. 73 — Inspection of the work while still set up in the machine is as accurate and far more efficient than any alternative method.

## HOLES, CONTOURS AND SURFACES

of holes to the coordinate layout with an indicator, inspection can be completed in far less time *than by any other means*, simply by using the accurate measuring system of the machine as a standard, Fig. 73.

The possible objection that work should not be inspected by the same equipment used to produce it is not valid in reference to the Jig Borer, for a variety of reasons:

1. The workpiece is already oriented in the machine, and any attempt to reorient it for inspection, as on a surface plate, could easily introduce an error as great or greater than the one being sought.
2. The measuring system of the machine is *at least* as accurate as *any* shop standard which might be otherwise used for measurement.
3. Inspection of its own work can be accomplished on the Jig Borer without reference to non-functional surfaces of the piece, as usually required when measuring on a surface plate.

This eliminates another almost certain source of error.

The use of the Jig Borer solely as an inspection device is by no means uncommon; many have been purchased specifically for this purpose. The directness, ease and rapidity in achieving high accuracy of measurement with the Jig Borer make it far superior to almost any other inspection device of comparable capacity — a factor which has prompted large plants to buy Jig Borers without spindle motors to prevent their use for any purpose other than inspection. No modifications have been suggested, even after years of use in the role of inspection, which would indicate their complete suitability. See also Chapter 13.

**Accessories** — Accuracy of the degree built into the Jig Borer can very easily be diminished by the lack of suitable tools and acces-



Fig. 74 — Second only to the effectiveness of the accessories themselves is their convenient availability. This desk-type cabinet provides a handy "tool crib" for the machine.

## JIG BORING PRINCIPLES AND APPLICATIONS

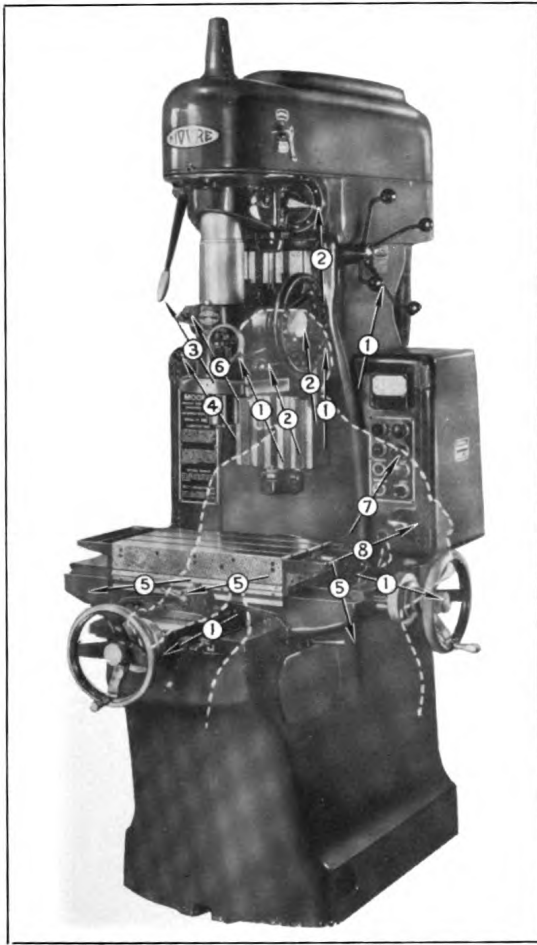


Fig. 75 — Operator, from normal sitting position, can reach all of the machine controls.

sories or the use of unsuitable ones. Moore accords this aspect of location a degree of importance equal to the care and thought it gives to the basic design and manufacture of the machine itself.

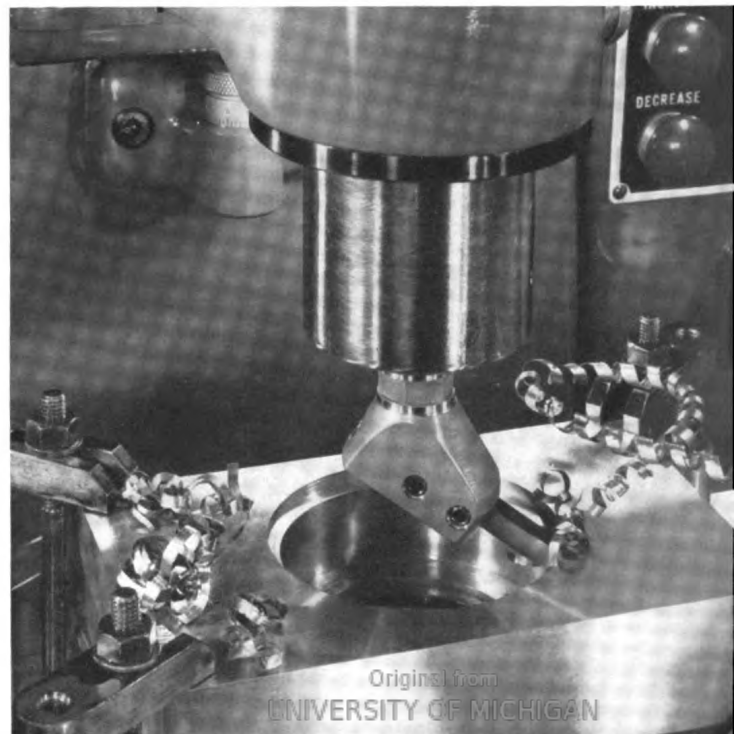
A full line of accessories and tools, engineered to complement the machine in each of its functions of locating, setting up, machining and inspection, are available. There are also specially designed cabinets, with a space for each item, Fig. 74. The desk-type cabinet serves both as a working tool-crib for the machine during use and as a storage cabinet. Thus the proper tool is always available at the machine when needed, avoiding make-shift improvisations.

### DESIGN FEATURES

In this chapter the Jig Borer has been presented as a generic machine tool for tool-making, model work, production and inspection. Repeated reference has been made to overall efficiency, rate of stock removal and convenience of operation. Direct reference to specific design features of the Moore Jig Borer will show how they contribute to these results.

Since the larger, more modern Model No. 2 Moore Jig Borer incorporates all of the features so thoroughly demonstrated in the 1,400 Model No. 1 machines in use, besides

Fig. 76 — In spite of its accuracy and sensitivity, the Moore Jig Borer need not be "babied" on heavy cuts.



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*Fig. 77 — The "Moore Shank" is recognized as providing the fastest, most accurate system of Jig Borer tool change. This feature is equally important in toolroom or production line.*

## JIG BORING PRINCIPLES AND APPLICATIONS

several not found in the simplified, earlier model, it will be used in reference.

Designed to fulfill all the requirements of the job categories already cited, the following outline of its design concept illustrates points which must be taken into account:

1. Table surface and travels must be large enough to accommodate the anticipated range of work without losing convenience in handling the numerous small workpieces normally encountered.
2. The operator should be able to reach all controls from a sitting position, Fig. 75.
3. The spindle should be sensitive enough to permit drilling very small holes, yet rugged enough to be accurate while taking very heavy cuts, Fig. 76.
4. Tool changing should be quick and accurate, Fig. 77.
5. It should be possible to attain the optimum spindle speed and feed ratio for any operation on any size hole within range of its capacity.



*Fig. 79 — Table positioning is controlled by accurate lead screws set to handwheel dial graduations. Reference scales provide a double check on location.*



*Fig. 78 — Any speed from 75 to 2,400 rpm is available by the push of a button. Speed is increased or decreased as one would press the accelerator of a car, reading the result on a panel tachometer.*

Rapidity and convenience in accomplishing this contribute much to overall machine efficiency, Fig. 78.

6. Measuring and positioning system must be accurate, direct, easy to visualize and rapid-to-set to minimize possibility of operator error, Fig. 79.
7. Need for servicing and adjustment must be held to a minimum.
8. Accuracy must be maintained in ordinary shop working conditions; no "pampering" similar to that given laboratory instruments of comparable accuracy is necessary.

Table size of 10" x 19" and travel of 10½" x 16½" x 10" were specifically determined to meet the maximum number of toolroom and production applications. While it is true that no machine is ever large enough to accommodate *every* job encountered, a massive machine is a continual handicap except for the very occasional outsize job.

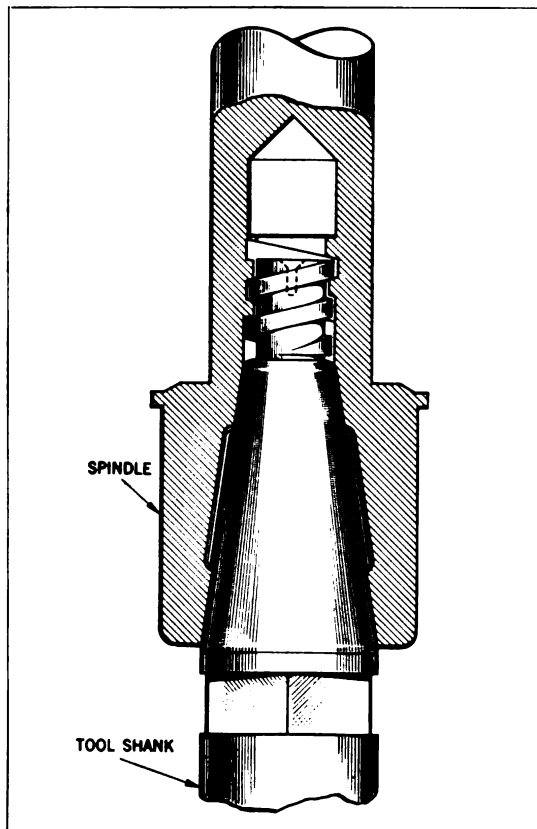


Fig. 80 — The draw-in element of the Moore shank, the square cut thread, does not influence location of the taper within the spindle.

Convenience of all controls to the normal sitting position of the operator is an important consideration, since fatigue can easily contribute to error. Note in Fig. 75 how accessible are:

1. All handwheels
2. Feed control and clutch
3. Brake
4. Quill housing clamp
5. Table and slide clamps
6. Adjustable depth stop
7. Speed control
8. One-shot lubrication

The spindle and quill assembly in any Jig Borer must necessarily share responsibility with the measuring system for locational accuracy. In addition, it is solely responsible for the accuracy of size and geometry of the hole produced. The design and construction of this assembly in Moore machines feature the following characteristics:

1. The spindle itself is made of a high-grade tool steel, selectively heat-treated for maximum hardness at the tool end and high tensile strength throughout.
2. This spindle is mounted in two *pairs* of specially selected, super-precision ball bearings within the quill. The entire assembly is preloaded to 200 pounds for rigidity.
3. The hardened, ground and lapped quill is grease-packed and sealed against dirt for life-time lubrication of bearings.
4. The quill itself is supported in two hardened, ground and lapped bushings in the nickel-alloy housing.
5. The rack, for vertical positioning of the quill, is a separate piece set into the quill; this provides a maximum of quill bearing area, and permits lapping of the quill and bearings to a fit in the bushings so that wear is eliminated as a factor, and no adjustment is ever necessary.

The Moore shank is acknowledged to provide by far the quickest and most accurate method of changing tools in a Jig Borer, Fig. 80. In many Jig Boring jobs, quick tool-changing is a significant factor in the total floor-to-floor time. This is equally true for both toolroom and production work.

Infinitely variable spindle speed, delivering the 2 hp of the drive at the ideal speed

## JIG BORING PRINCIPLES AND APPLICATIONS

for any operation, Fig. 81, contributes much toward stock removal efficiency, tool life and surface finish. This is controlled by a push button on the panel and read on a tachometer, making it easy to attain the ideal speed for any operation and repeat it when desired, which is so important in production jobs.

The combination of a rectangular positioning system, controlled by precise lead screws, and visually represented by reference scales is

so natural in operation that operator error is reduced to a negligible factor.

Despite design forethought to minimize the effect of the human element, it cannot be denied that sound Jig Boring *operating practices* inevitably play an important part in the quality of work produced. The following chapter promotes the adoption of practices which have been proved to produce the most satisfactory results.

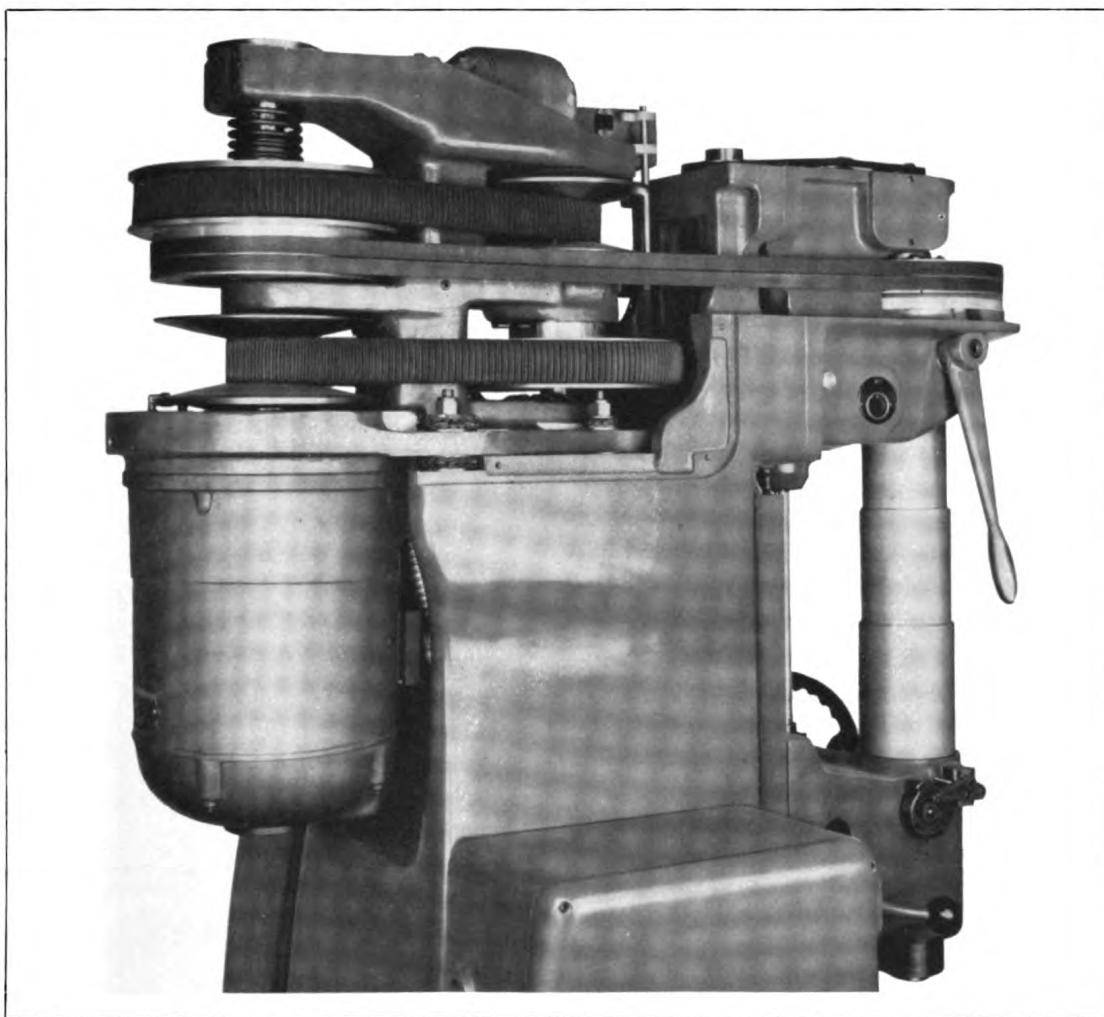


Fig. 81 — Speed variation in the Moore VEE drive is accomplished by positive displacement of sheave halves through a push-button controlled ratio motor. It provides the following advantages:

1. Smooth, stepless control through entire range.
2. Simplicity and accessibility of all parts.
3. Ample capacity to transmit full horsepower and torque of motor.
4. Avoidance of gears eliminates the most common cause of spindle chatter.



*Jig Boring Practices.*

## JIG BORING PRACTICES

SINCE complete automaticity is an unlikely prospect for machines performing *non-repetitive operations* on dissimilar workpieces, the human element cannot be overlooked in any discussion of Jig Boring. An operator's working habits and his knowledge of the principles involved play an important part in the results obtained from a Jig Borer. True, there is little opportunity for him to coax more accuracy from the machine than is built into it, but there is always the danger that the reverse may occur.

What follows is a general outline of sound operating practice. It is not possible, naturally, to anticipate in print all combinations of requirements and conditions encountered in specific jobs.

**Setting Up the Workpiece** on the machine table establishes its *geometric* relationship to the measuring system and the spindle axis. Although a number of variations are possible, the more common requirements include:

1. Parallelism between the surfaces or axis of the workpiece and the machine table, and the alignment of one edge or axis of the workpiece with the direction of table travel.
2. Angular inclination of the workpiece to table surface.
3. Workpiece rotatably mounted to permit angular spacing of holes, the axis of rotation being parallel to the spindle axis or inclinable at any desired angle to 90°.

The proper positioning of the workpiece and its clamping, or restraint, against undesired movement during machining constitute

the first step in any Jig Boring job. Typical examples falling into case 1 will first be discussed.

By far the most common type of workpiece is the rectangular, flat section. Orientation presents no problems; yet frequently errors in the finished workpiece can be traced back to improper technique in the preliminary setup.

In order to avoid machining into the table surface itself, it is usually necessary to support this type of workpiece on parallel pieces. Although there is no objection to the use of accurately ground and paired parallels of conventional shape, the parallel setup blocks, Fig. 82, frequently prove to be far more convenient, particularly since they provide a large choice of heights and strategic placement of support, so that interference with the position of holes is avoided, Fig. 83. These blocks are so made that their matching dimensions are alike within extremely close limits, permitting their use in combination and as matched sets. Convenient clearance and tapped holes facilitate their attachment to each other, to the table, and the direct mounting of the workpiece when desirable.

Work too large to allow for clamping directly to the table can be mounted on the extension parallels, Fig. 84. These support the piece and provide T-slots for conventional clamping with bolts and straps.

While it may seem obvious, the importance of clamping *directly* in line with, or over, the support cannot be over-emphasized. Any

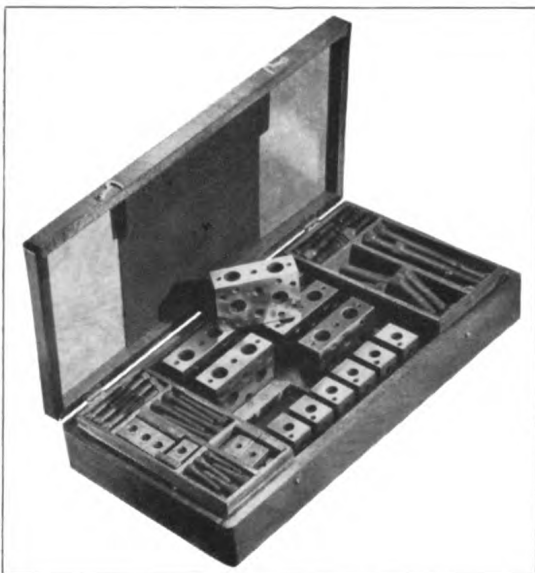


Fig. 82— These blocks are available in sets of six of each of two sizes, 1" x 2" x 3" and  $\frac{7}{8}$ " x  $1\frac{1}{4}$ " x  $1\frac{1}{2}$ ". These dimensions are held within  $\pm .0001$ " and squareness within .0002".

pressure exerted on an unsupported portion of the workpiece will inevitably induce a twist or bow and the condition illustrated in Fig. 85. Similar difficulty is encountered in attempting to clamp work which is not flat.

The set of bolts, straps and heel-rests shown in Fig. 86 are designed to provide an efficient means for clamping a wide variety of work. Their conventional use is shown in Fig. 87, the brass heel-rests straddling the table T-slots and opposing the clamping pressure without marring the table surface. Extension pieces are for use with higher work, such as box jigs.

The second requirement, i.e., alignment of one edge of the work with table travel, can be met in several ways. A straightedge, parallel to the travel, is provided at the edge of the table. The workpiece can be set directly against this or, if desired, spaced away by parallel pieces such as gage blocks or parallel setup blocks, Fig. 88.

The alternative method involves use of an indicator held in the spindle nose by means of the indicator holder, Fig. 89. With the indicator point brought into registration with the

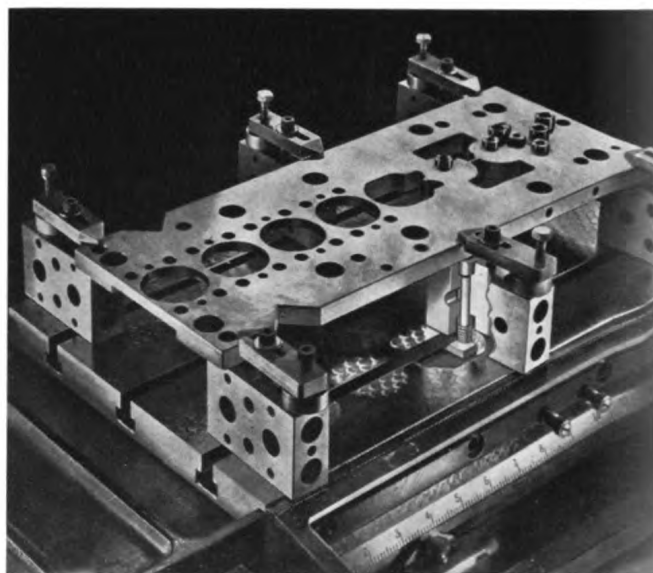


Fig. 83— Blocks may be positioned to provide support for long workpieces without interfering with machining locations.



Fig. 84— Extension parallels permit mounting and clamping workpieces larger than machine table.

edge of the workpiece, partial rotation of the spindle by means of the knurled diameter of

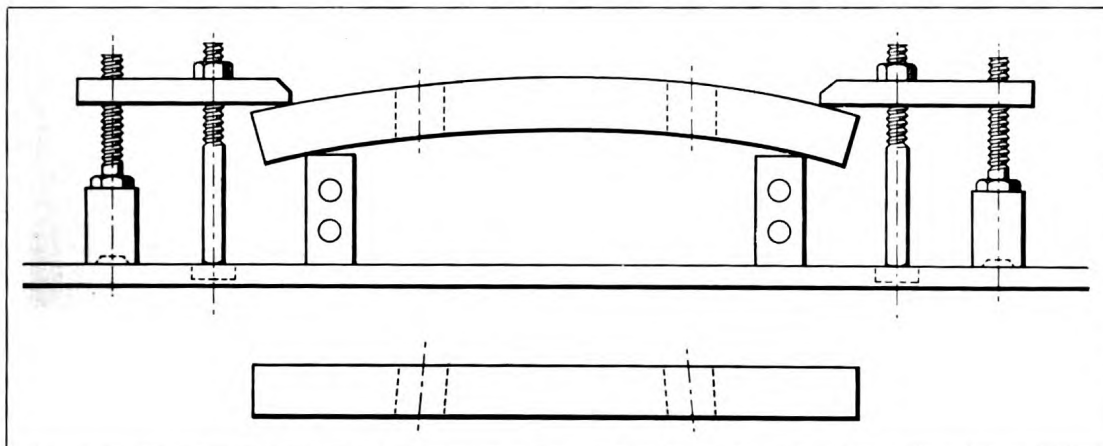


Fig. 85 — Spring induced by unsupported clamping will result in non-parallel axes of holes machined in such a setup.

the holder quickly establishes the proper position of the indicator with its movement normal to the edge of the piece. With the indicator in this relationship, traversing the table will move the workpiece edge past the indicator point. In this way the indicator will show the amount of misalignment; this can be eliminated by gently tapping the proper end of the work until the indicator shows no movement during the traverse. The clamping nuts should then be snugged down, and the alignment verified again to insure against an

unnoticed shift. Dimensional relationship of work to measuring system and spindle axis in each situation will be taken up later as a separate phase of the operations.

Flat, disc-type workpieces generally require no more than support on parallel blocks, without the need for any particular alignment or orientation. Cylindrical work is conventionally supported and aligned in V-blocks, Fig. 90. Should the length of the piece necessitate the use of two blocks, it is important that they be a matched pair to insure parallelism

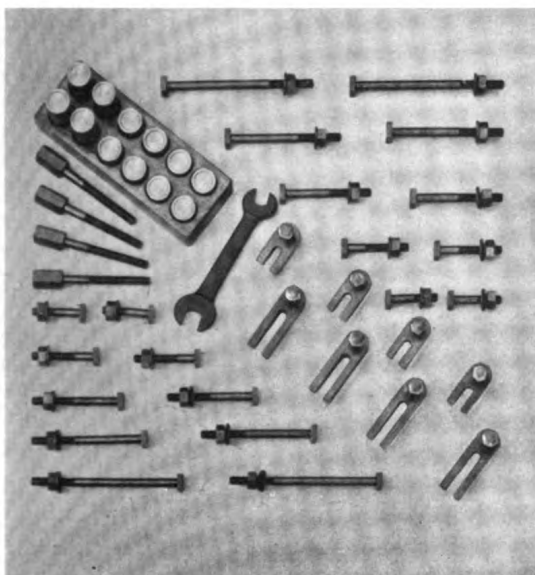


Fig. 86 — Bolts, straps and heel-rests provide the most convenient means for clamping.

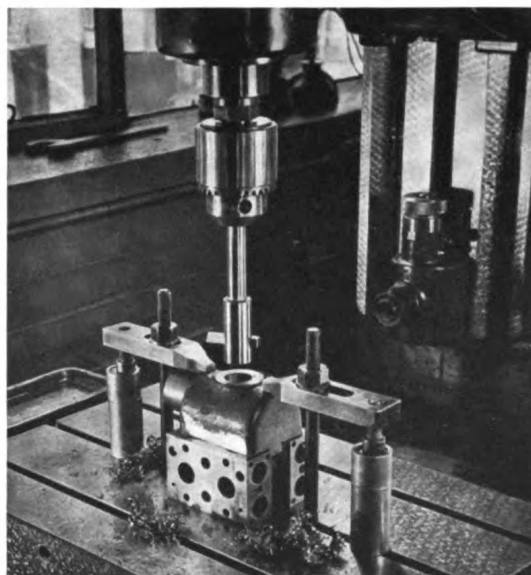
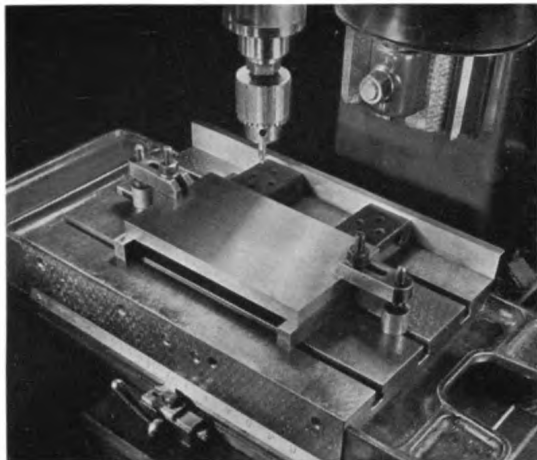
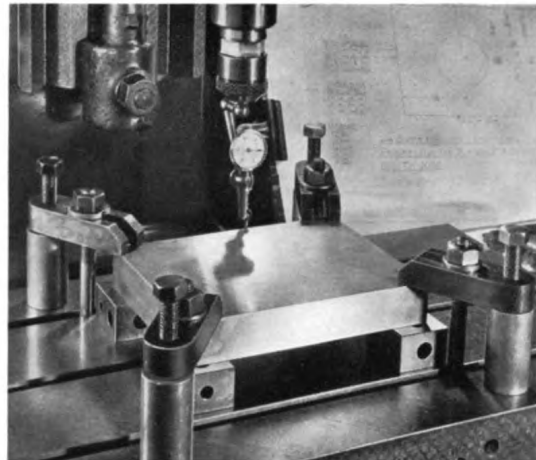


Fig. 87 — Effective clamping leaves tool area unobstructed, holds work securely and does not mar table.

## HOLES, CONTOURS AND SURFACES



*Fig. 88 — Setup blocks space work from straightedge, parallel to table travel.*



*Fig. 89 — Indicating edge of work parallel with table travel.*

*Fig. 90 — Work set up in V-blocks should, itself, be indicated as a final check on alignment before boring.*



of the cylinder axis with the table. Alignment of this axis with table travel is accomplished in much the same manner as described for flat work, indicating along the diameter of the cylinder and correcting by tapping the V-block.

Angular inclination of the workpiece to the table surface and spindle axis, case 2, is most accurately done with the micro-sine plate, Fig. 91. Based on the familiar sine bar principle, this accessory provides an inclinable surface of adequate proportions for the attachment of even rather large work. Any desired angle from  $0^\circ$  to  $90^\circ$  can be accurately established by the insertion of a gage block or blocks, selected by reference to the simple formula on the plate. A non-influencing clamp secures the setup against movement during machining.

Normally the edge of the micro-sine plate

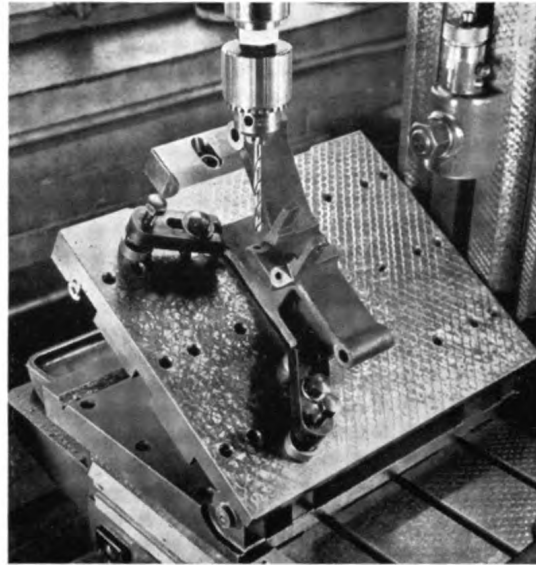


Fig. 91 — In addition to accurately establishing the angular position of the work, the micro-sine plate provides adequate mounting and clamping surface.



Fig. 92 — The combination of rotary table and micro-sine plate is employed in compound angle setups and for index spacing of such setups.



Fig. 93 — This mounting position of the No. 2 Moore Rotary Table is convenient for radial hole spacing.

and the work are both aligned with the table travel. However, special circumstances may require the development of a compound angular relationship, in which case a rotary table is mounted on the micro-sine plate. By attaching the work to the rotary table top, any desired compound angle can be attained by the combination of the two available angular movements, Fig. 92.

Machining a number of holes angularly spaced and equidistant from a common point can be done from either rectangular or polar coordinates (see Chapter 5). In the former, the setup is described under case 1; in the latter a rotatable, angular spacing accessory, the rotary table, is used.

Should the axis of the hole be required at an angle to the axis of rotation, the rotary table can be mounted on the micro-sine plate, as previously described. Radial holes  $90^\circ$  to the axis of rotation can be produced by mounting the rotary table as shown in Fig. 93.

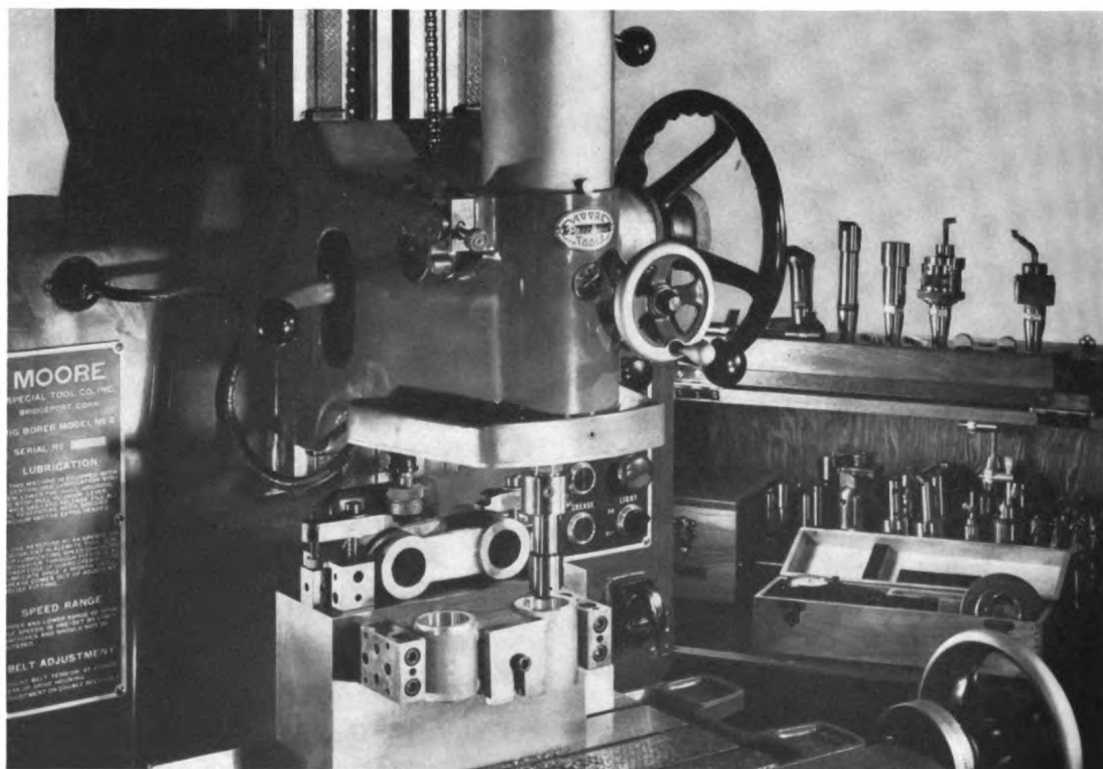


Fig. 94 — Parallel setup blocks serve as locators in this simple but effective two-position fixture for milling and boring a production part on the Jig Borer.

## JIG BORING PRACTICES

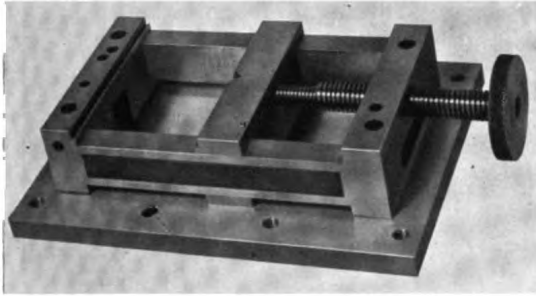


Fig. 95 — Precision vise.

The preceding discussion has been largely concerned with the setup of one-time jobs. For repetitive work there are several ways in which a lot of time may be saved. For example, simple but effective nests or locations may be assembled from the parallel setup blocks, using them for support as well as location, Fig. 94.

The precision vise, Figs. 95 and 96, is valuable in this type of work, the stepped jaws

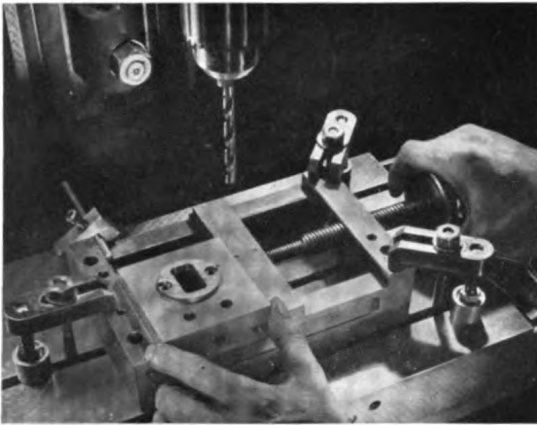


Fig. 96 — Easily attached end-stops adapt the vise to production work.

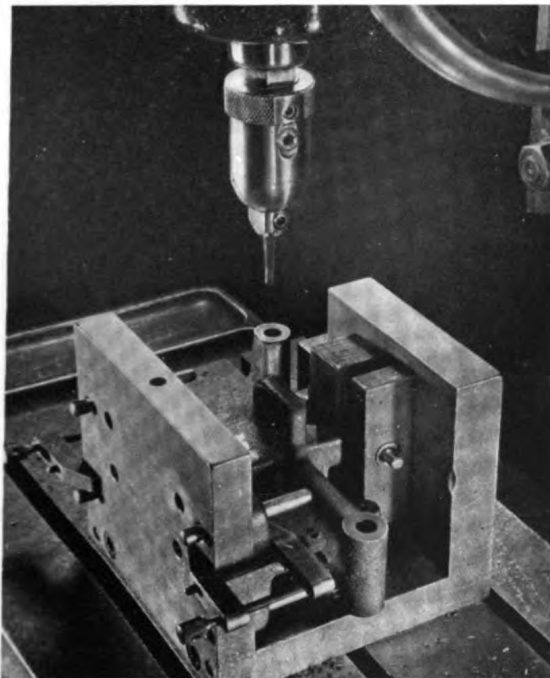
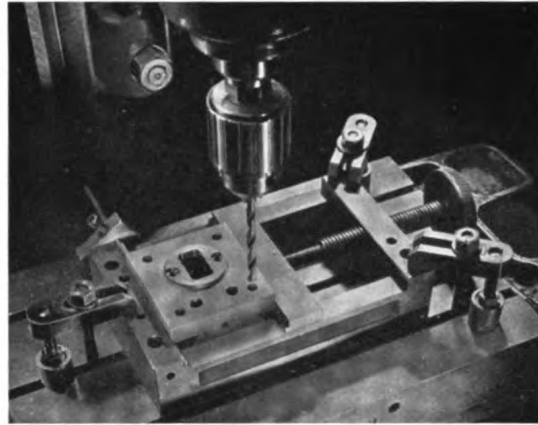


Fig. 97 — Special work-holding fixtures "pay off" in production Jig Boring.

serving both as parallels and for clamping. A V-slot is provided for round work. The fixed jaw, ground square and parallel to the base

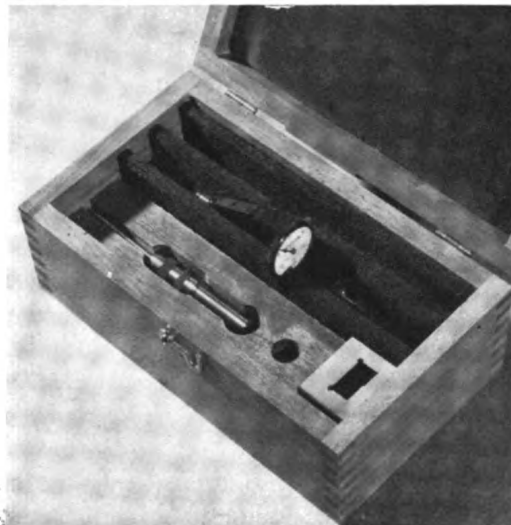


Fig. 98 — This indicator set consists of an indicator (horizontal or vertical dial, .001" or .0001" graduations), a jointed indicator holder, a line-finder and an edge-finder.



Fig. 99 — The indicator holder permits a wide range of adjustment, yet remains firmly positioned as set.

plate, facilitates registration of the workpiece.

In small-lot or quantity production, a specially designed work-holding fixture often pays for itself in a short time, particularly in the case of unsymmetrical or odd-shaped parts, Fig. 97.

Undue wear of table surface and ways can be avoided by developing the habit of setting up jobs on the ends and corners of the table as well as in the center. In this way wear is distributed, and often an emergency or rush

job can be set up and machined without disturbing the workpiece already in place.

**Dimensional Pickup** — Now the workpiece is geometrically oriented to the machine's travel. The next step requires establishing its *dimensional* relationship to the measuring system and spindle axis. Since the required reference may be to an edge, pin, boss, hole, scribed line, slot or contour, a variety of pickup techniques must be employed.

In setting dials or positioning the table, movement must always be made in the direction indicated by the arrows on the dials, in order to eliminate backlash. If it is necessary to re-approach a setting, back away from the setting by several thousandths. Then make the setting again from the correct direction.

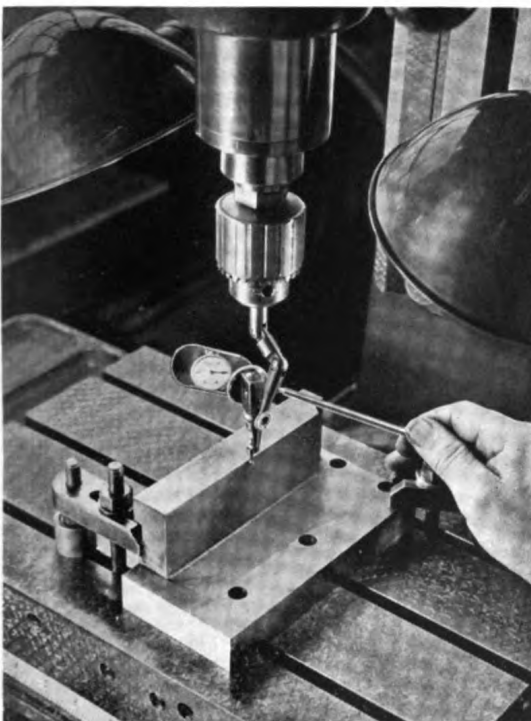
The indicator set, Fig. 98, includes the equipment necessary to meet most of these conditions. The indicator itself is supported by an adjustable, jointed arm, from either the indicator holder or drill chuck held in the spindle, Fig. 99. The flexibility of this arrangement permits a considerable latitude in positioning the indicator to suit the workpiece.

The most common requirement — reference to an edge — can be accomplished most easily and accurately by use of the edge-finder, Fig. 100. This accessory is so constructed that its surface registering against the edge of the work is precisely central to the edges of the .400"-wide slot provided for pickup with the indicator. The edge-finder is held firmly against the work; the table is positioned so that the indicator shows an equal reading when rotated to contact the opposite, inside edges of the slot. At this point, the edge of the piece will be exactly in line with the spindle axis. A known relationship is thus established to the measuring system. This may be checked by moving the table .200" and indicating the edge of the piece itself, Fig. 101. In this way, any failure of the edge-finder to register properly, due to a burr or irregularity on the work, will be detected.

A somewhat less convenient and less accurate method picks up an edge without the use of an edge-finder. Reference to Fig. 102



*Fig. 100 — Picking up an edge with the edge-finder and indicator. The mirror provides a convenient means for reading the vertical dial indicator as it faces away from operator.*



*Fig. 101 — Indicating directly against workpiece after use of edge-finder automatically checks the pickup.*

will show that the necessary vertical movement exaggerates any edge deviation.

Holes, pins, bosses and radiused contours are generally capable of single and direct pickup by means of an indicator. A scribed line or point requires a different instrument. Usually the relative inaccuracy of such a reference makes it unnecessary to use a more refined device than the line-finder or wiggler shown in Fig. 103. Held in the rotating spindle, its point can be made to run true by a touch of the finger. It is then brought close to the line or mark on the work, which is positioned directly under the point as observed through a glass. This method may also be used for locating an edge which may not, in itself, be sufficiently accurate to justify greater precision of location.

Occasionally the reference point on the work will present conditions not readily suited to use of the indicator and requiring greater accuracy than is attainable with the line-finder. Very small or partial holes, irregular contours, slots and punch marks fall into this

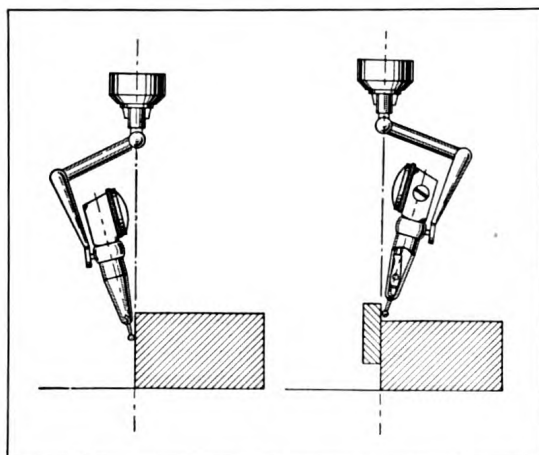


Fig. 102 — Picking up edge without edge-finder. Indicator is set against edge of workpiece, raised and rotated 180° to touch gage block held against edge.



Fig. 103 — Picking up end of die block with line-finder.

category. A satisfactory solution is available in the locating microscope, Fig. 104. This instrument combines several unusual features essential to its use for this purpose, including:

1. A roof prism which reverts the image to its natural position, so that positioning is a normal movement to the operator.
2. Its field of vision is large enough,  $\frac{1}{4}$ " diameter, to encompass an adequate area of the work.
3. The X40 magnification is sufficiently great to permit a "tenth" to be seen.
4. The reticle reference consists of a number of concentric circles and two pairs of crossed center lines, suitable for a wide variety of requirements.

5. An adjustable optical axis which may easily be brought into coincidence with that of the spindle.

The important role played by the microscope in the use of a Jig Borer as an inspection device will be discussed more fully in Chapter 13.

**Machining** — It is in the machining operation itself that the widest choice of methods is available. It is not often possible to clearly establish the superiority of one over the other. The choice of cutting tool systems may be compared to the choice between roads, all of which converge at a common destination. This goal represents the highest order of geometric, locational and dimensional accuracy, attainable only through single-point boring. Should something less accurate suffice, it merely means stopping short on one of the chosen roads. An attempt will be made to show this in practice by the following discussion of tools and techniques.

The usual practice in starting a hole is to



Fig. 104 — The Moore Locating Microscope permits optical pickup where conventional mechanical means are impractical.

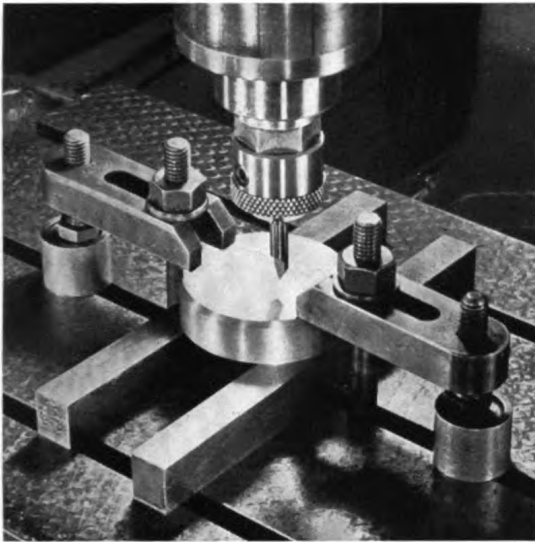


Fig. 105 — Special spotting tools provide high initial locational accuracy, important where hole is not to be finished by single-point boring.

employ a center drill. In the case of holes to be finished by end reaming, or those too small to bore, a special spotting tool, Fig. 105, should be employed to provide higher initial accuracy. The three sizes of special Jig Borer drill chucks, Fig. 106, are suitable for holding these tools, as well as the various drills required in each operation.

Holes smaller than about  $\frac{1}{16}$ " may be finished with satisfactory accuracy by drilling directly from the spotted location. Larger holes can be rapidly opened up to within a few thousandths of finish size, using the minimum number of drills in the process.

To extend the range of standard drills below  $\frac{1}{2}$ ", which should be available with each machine, and because straight shank drills over  $\frac{1}{2}$ " are made in lengths too great for use in a Jig Borer, Moore has established a special series of short drills in fractional sizes from  $\frac{1}{2}$ " to  $1\frac{1}{2}$ ", Fig. 107. Possible damage to the finely finished  $\frac{1}{2}$ " end reamer collet is avoided by making the shanks of these drills a few thousandths too large to enter the collet, thereby insuring the use of the special  $\frac{3}{4}$ " chuck provided for the purpose.

Roughing may be continued beyond the range of available drill sizes by a variety of



Fig. 106 — Drill chucks of standard design but of precision quality are fitted to Moore shanks.



Fig. 107 — Special Jig Borer drills and spotting tools: Straight Shank Drills

Two Front Blocks — 15 reamer drills for end reamers from  $\frac{1}{8}$ " to  $\frac{1}{4}$ ", and appropriate spotting tools.

Center-Left Block — 24 special short drills, 5" long, with  $\frac{3}{4}$ " straight shank, in  $\frac{1}{16}$ " increments from  $\frac{1}{2}$ " to 1.

Rear Block — Eight short drills, 7" long, with  $\frac{1}{2}$ " straight shank in  $\frac{1}{16}$ " increments from  $1\frac{1}{4}$ " to  $1\frac{1}{2}$ ".

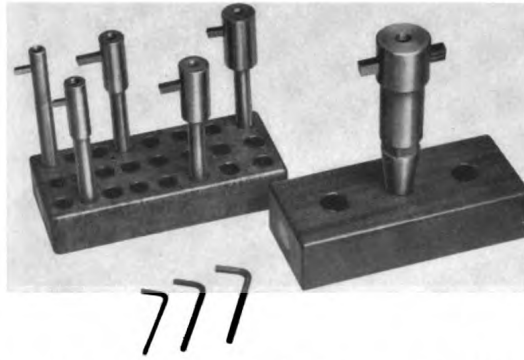


Fig. 108 — Sweeping tools for facing and rapid hole enlargement. Overall length of straight shank models is 5".

Pilot diameter	Max. sweep diameter
$\frac{1}{2}$ "	$1\frac{3}{4}$ "
$\frac{5}{8}$ "	$1\frac{3}{4}$ "
$\frac{3}{4}$ "	$2\frac{1}{2}$ "
$\frac{7}{8}$ "	$2\frac{1}{2}$ "
1"	3"

The Hole Hog (at right), fitted with Moore shank, is used for enlarging holes from  $1\frac{1}{2}$ " to  $2\frac{1}{2}$ ". (See chapter frontispiece.)

boring tools. The "Hole Hog," designed for this purpose, is particularly efficient in its rate of stock removal in larger holes. A series of similar sweeping tools, Fig. 108, are equally efficient in rapidly enlarging holes or for sweeping or facing operations on surfaces and bosses. Pilots of sweeping tools are made to fractional sizes and, being hardened and ground, will not damage a previously finished hole when used to sweep a boss.

Spotters, drills and end reamers are shown in Fig. 109; when held in a collet, they provide the fastest system of locating, drilling and reaming holes on a Jig Borer. The spotters establish locational accuracy, the special undersize drills leave from .005" to .015" for final sizing by means of the end reamer.

Before passing on to the subject of intermediate and/or finishing cuts, it might be well to point out that these generally account for most of the time per hole. Therefore, in the interest of efficiency, it is advisable not to start them too soon; that is, rough to within as close to finish size as is practical.

Although not matching the accuracy of the slower single-point boring, two types of

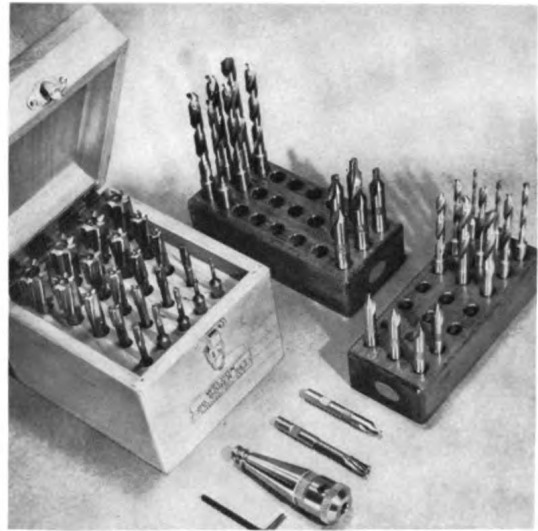


Fig. 109 — Spotters, Drills and End Reamers

Much time can be saved with the Moore Straight Shank method by using spotters, reamer drills and end reamers, each with the same size straight shank. Each tool is held in the collet with a set screw and it is not necessary to change this collet between operations; each tool can be quickly withdrawn and replaced. This method represents the fastest system of locating, drilling and reaming holes on a Jig Borer.



Fig. 110 — Straight Shank End Reamers

Left Set — Complete set of 21 end reamers with  $\frac{3}{8}$  and  $\frac{1}{2}$  shank, from  $\frac{1}{8}$  to  $\frac{1}{2}$  in increments of  $\frac{1}{16}$ ; from  $\frac{3}{16}$  to 1 in increments of  $\frac{1}{16}$ .

Right Set — Complete set of eight end reamers with  $\frac{5}{8}$  straight shank, in increments of  $\frac{1}{16}$  from  $1\frac{1}{16}$  to  $1\frac{1}{2}$ .

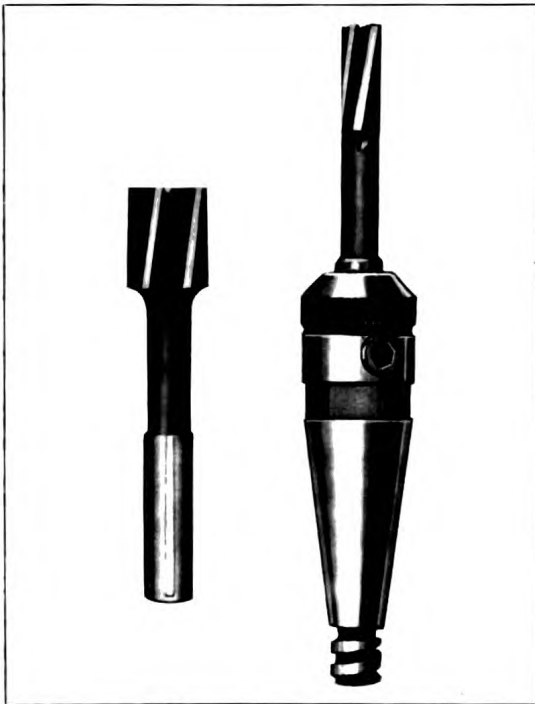


Fig. 111 — Five collets,  $\frac{3}{8}$ ",  $\frac{1}{2}$ ",  $\frac{33}{64}$ ",  $\frac{5}{8}$ " and  $\frac{9}{16}$ ", are hardened, ground and lapped to run true within .0001". This range of sizes is designed to accommodate all available end reamers and suitable drills.

end reamers provide a favorable compromise, i.e., a considerable saving of time at an often permissible, minor sacrifice in accuracy. The end reamer, held rigidly and running true with the spindle, acts somewhat like the combination of a boring tool and a reamer, locating and sizing at the same time. This hybrid tool does not achieve perfection in either respect, for a slight runout tends to make it cut slightly oversize. Gently clipping the corners of the teeth with a stone improves this condition, but somewhat reduces the end reamer's ability to establish location. With reasonable care, however, an operator should be able to hold size and locational errors to within  $\pm .0005$ ".

End reamers are available in sets from  $\frac{1}{8}$ " to  $1\frac{1}{2}$ ", in increments of  $\frac{1}{32}$ " or  $\frac{1}{16}$ ", Fig. 110, for the Moore Jig Borer. In addition to these fractional sizes, a set .008" to .012" undersize, together with suitable reamer drills, is recommended for sizing holes later to be ground.

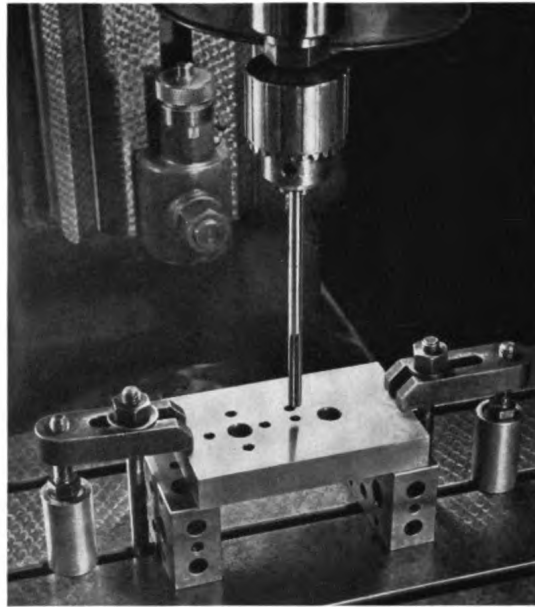


Fig. 112 — Rose or fluted reamer reaming a previously bored hole to size.

End reamers are held in collets, Fig. 111, the locating bore of which is ground and lapped to a plug-gage fit to the reamer shank. For the highest accuracy, it is sometimes desirable to peen the reamer shank slightly to make them run true in the collet, indicating from the teeth.

Ordinary rose or fluted reamers, differing from end reamers in the relative flexibility of shank which permits them to align themselves with the hole, are often a satisfactory

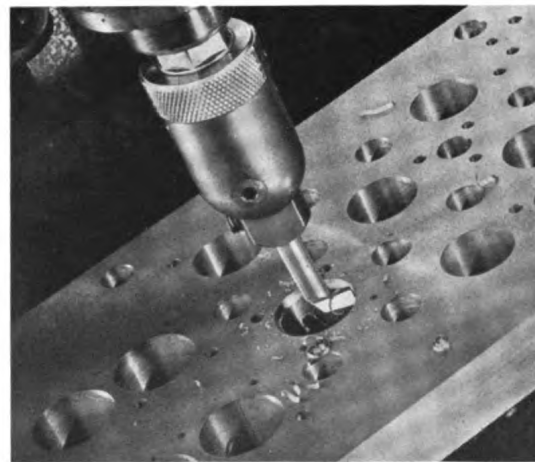


Fig. 113 — Boring chuck of the swivel block type.

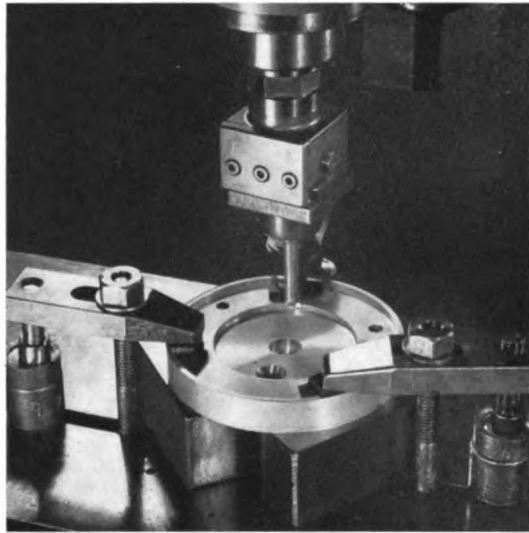


Fig. 114 — Boring chuck of the dovetail offset type.

means for sizing a hole, Fig. 112. Carefully handled, and removing between .001" and .003" of stock, these tools will produce somewhat better accuracy of hole size than the end reamer. Either type of reamer has the advantage of avoiding the cut-and-try adjustment necessary with a single-point boring tool, but cannot produce the infinite range of sizes possible with the latter.

The importance of single-point boring as the most accurate method of attaining locational accuracy in Jig Boring amply justifies the wide range of boring tools available.

Size control in single-point boring is dependent on a means of adjusting the position of the tool point outward from the axis of spindle rotation. Two types of boring chucks provide this adjustment through different means. The swivel block type, Fig. 113, offers the widest range of adjustment for its diameter, a decided advantage in working in close quarters, such as in deep box jigs or close to die posts.

A disadvantage frequently noted in this type of chuck lies in the fact that adjustment of the tool moves it in an arc, thus the graduations on the adjusting screw do not bear an exact relation to the tool movement. As a matter of fact, this is not so serious a problem as might be anticipated since the graduations



Fig. 115 — Moore shank, solid type, "thousandth setting" boring bars (top) are available in two lengths for holes from  $\frac{1}{8}$ " to  $\frac{3}{4}$ " diameter. Moore shank, "Micro tenth-setting" boring bars covering the same range of hole sizes are available in short length only.

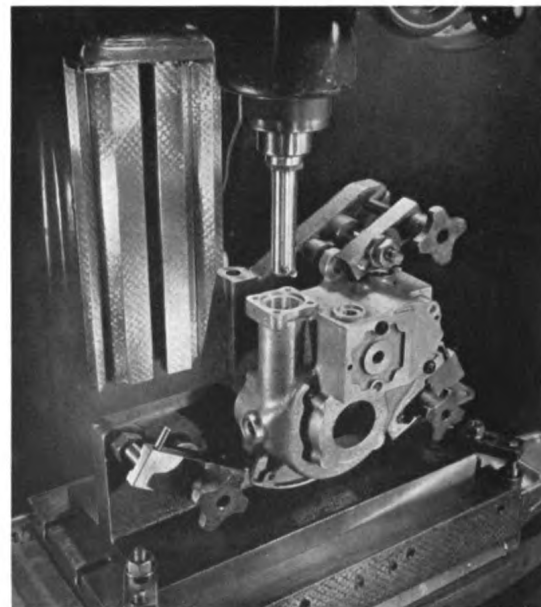


Fig. 116 — Jig Boring deep hole with solid type boring bar.

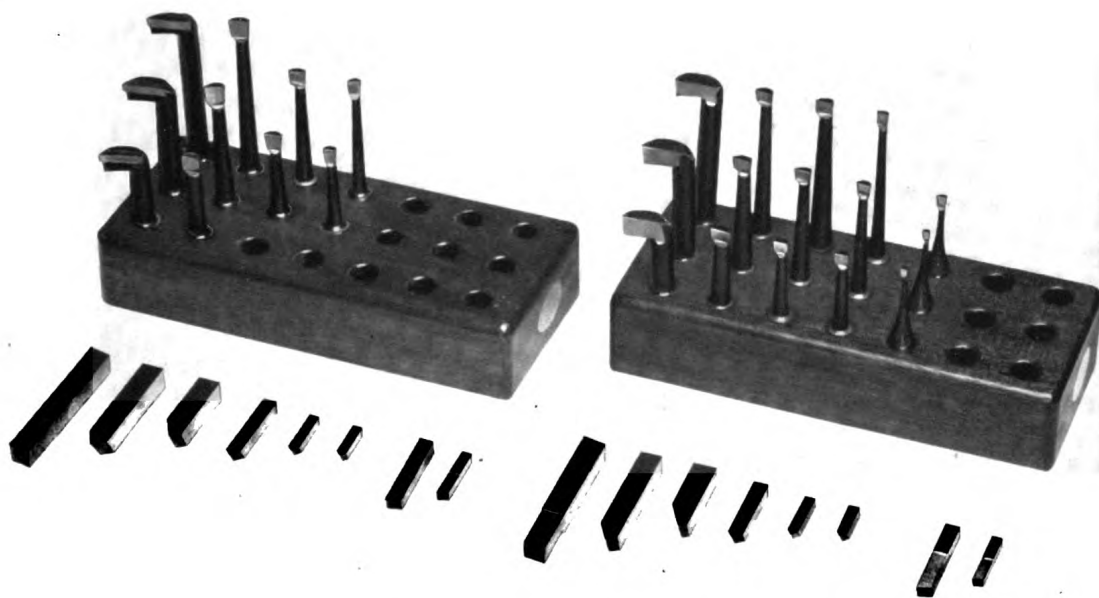


Fig. 117 — Boring bits for chucks, boring bars and sweep tools.

— quite accurate over a short range, provided tools of proper length are used — would hardly be depended upon over a long range of travel.

From a purely functional standpoint, the extreme rigidity resulting from a large clamping surface, together with the inherently clean design, make it very reliable in operation.

The dovetail offset type of boring chuck, Fig. 114, is somewhat shorter than the swivel block. As an added advantage, the tool is moved directly outward in a straight line by the adjusting screw. This permits the rise of odd-length tools without altering the value of the graduation, although the range does not equal that of the swivel type. Due to this same straight-line movement, this chuck is convenient for squaring shoulder and facing bosses.

Due to the necessary cut-and-try method of adjusting any boring tool, there is definite advantage in being able to leave the adjustment set to cut to a particular size for repetitive work. To this end, a series of boring tools, shown in Fig. 115, has been developed. These boring bars are of the solid type and are adjustable over a relatively short range by means of graduated screws. The series covers a range

of hole sizes from  $\frac{1}{2}$ " to  $3\frac{1}{2}$ ". They are particularly useful in deep-hole boring, Fig. 116.

Carbide tools are very efficient for some types of Jig Boring operations, particularly in boring aluminum and cast iron, or for production work. Therefore, in addition to the set of high-speed tool bits shown in Fig. 117, duplicate sizes are available tipped with carbide.



Fig. 118 — The 36 leaf taper gages are graduated in thousandths and cover a range from .095" to 1.005".

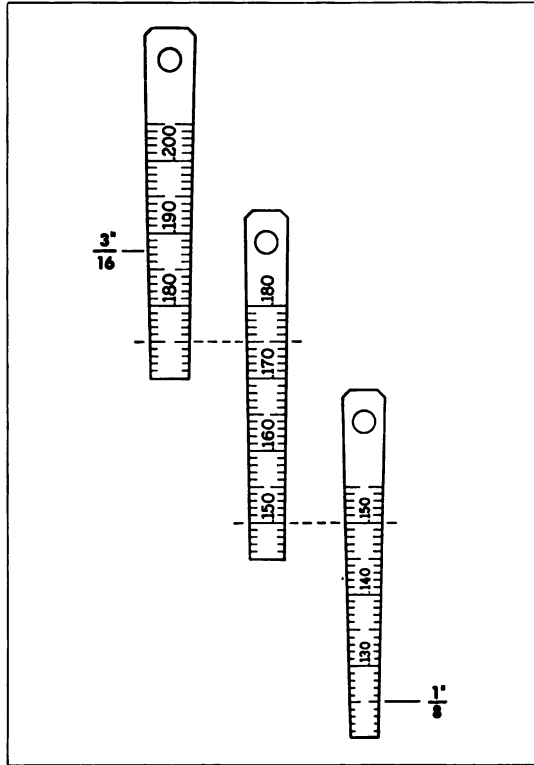


Fig. 119 — Graduations on each Moore leaf taper gage overlap the next by .010".

Variation in the machinability of commonly encountered materials, together with the difference in spring or deflection of various types of boring tools, make experience the only practical way to master the technique of boring to size. Implied in any discussion of finishing and sizing, however, is the attendant problem of measurement. *In a very real sense, it may be said that the ability to measure accurately is the most important factor in the ability to size accurately.*

**Measurement** — Relatively accurate measurements of hole diameter can be made with the familiar inside caliper. When it is set to touch the sides of a hole, the dimensions may be read on a micrometer. Slightly more accurate results may be had by substituting a telescopic gage for the caliper.

More accurate than either of these is the plug gage, but it can only measure a hole whose size is exactly that of the gage. Unless an infinite range of gage sizes is available, it

cannot measure a hole before it is finished, nor determine how much stock remains to be removed. To overcome this limitation, a hole-measuring instrument, the flat leaf taper gage, Fig. 118, has been developed. This set of gages covers a range from .095" to 1.005", with the graduations at the end of each overlapping those of the next, Fig. 119.

As shown in Fig. 120, this type of gage contacts the hole at the top and, being short, conveniently clears cutting tools. Obviously it cannot determine errors in the geometry of the hole, i.e., bellmouth or taper; nor can such gages be read to a "tenth." They are invaluable for keeping track of size during roughing and as a guide to approaching finished size prior to plug fit.

Also capable of more flexibility in use than a plug, and of equal accuracy, is the indicating type gage, Fig. 121. Set against a micrometer or master ring, it readily shows deviation from true cylindricity as well as diameter of the hole.

**General Operating Practices** — While it is impractical to follow any prescribed set of rules in the operation of a Jig Borer, due to the wide variety of work sure to be encountered, the following general sequence should be followed whenever possible:

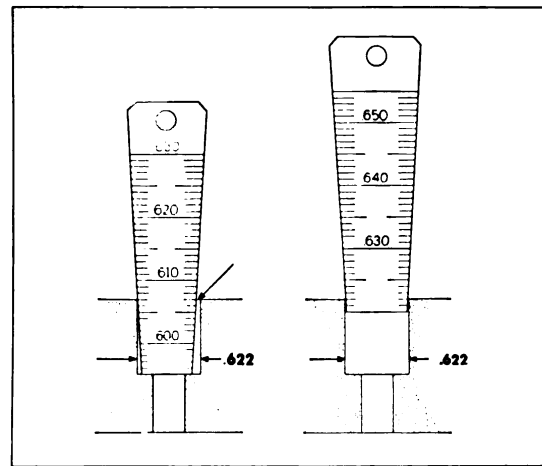


Fig. 120 — Size of hole is read from gage at point of contact with top edge of hole. Overlapping graduations on the large number of gages comprising the set eliminate interference from shoulders.



*Fig. 121 — Indicating type hole gages are not only more versatile as to size range than plug gages, but reveal the geometry of a hole.*

1. Set up the workpiece carefully to insure proper relation to machine travel.
2. Establish the dimensional relationship between the reference point on the work and the spindle axis. Relate this to the measuring system by setting the scales and dials as described in Chapter 5.
3. Spot the position of all holes lightly with a center drill.
4. Repeat step 3, re-spotting to the depth necessary to provide an adequate guide for the subsequent drilling operation. While step 3 may appear unnecessary, the re-spotting is good insurance against the most common operator error of misreading the scales by .100" or the dial by .010".
5. Rough all holes to nearly finish size *before* finishing any of them. Drilling or sweeping are the most efficient means for accomplishing this operation. Not only is the stock removed more rapidly than by boring, but less side thrust is exerted on the work, an insurance against shifting. When drilling large holes the size should be increased in steps of about  $\frac{1}{4}$ " to avoid pushing the inefficient center web of large drills through solid stock.
6. Go back and check the original setting of the work, step 2, to make sure it has not shifted during roughing. On particularly accurate work its temperature should be allowed to return to that of the room before making this check.
7. Finish-bore all holes to size. The final cut, unless an excessive amount of stock has been left from roughing, will not materially affect work temperature.
8. Check the location of each hole after having re-established the original reference. Indicating each hole from the spindle is an extremely sensitive and accurate method of inspection, since the reading shows *twice* the actual displacement or error of location.



*Jig Grinding Principles and Applications.*



## JIG GRINDING PRINCIPLES AND APPLICATIONS

THE JIG BORER, while it is adequate and efficient for hole location in *unhardened materials*, is incapable of performing this service in *hardened materials*. Here the problem is most critical.

Recognizing the need for a means of accurately locating and grinding holes to size, Moore pioneered the development of the Jig Grinder in 1940. This machine, utilizing the established principles of rectilinear positioning borrowed from the Jig Borer, together with planetary grinding, introduced a new concept of locational accuracy in hardened steel and carbides.

As first conceived, the Jig Grinder was primarily intended to position and grind cylindrical as well as conical holes, with the taper in either direction. Since that time, continuing development and user-experience have revealed a greatly expanded scope of applications for the Jig Grinder. The most significant trend has been toward the grinding of contours, typical of which are the stator-rotor lamination press tool parts, Fig. 122. These forms include combinations of radii, tangents, angles and flats, all of which must be accurately ground to size and location.

The desirability of Jig Grinding holes and contours to location and size, and with draft or taper if required, after the distortion of hardening, is attested by the following points:

1. Mating parts such as punches and dies can be

finished concurrently and made to figures rather than just "to fit." In addition to speeding delivery, this eliminates the tedious job of stoning and fitting. Equally important is the assurance that duplicate parts can be provided at any time.

2. Service life is greatly increased by grinding; because fits are more accurate, alignment is assured, and surface finish is improved. Full advantage of the quality of the steel is obtained by grinding the few thousandths of softer, decarburized skin resulting from hardening; thus a surface of maximum hardness and wear-resistance is attained.

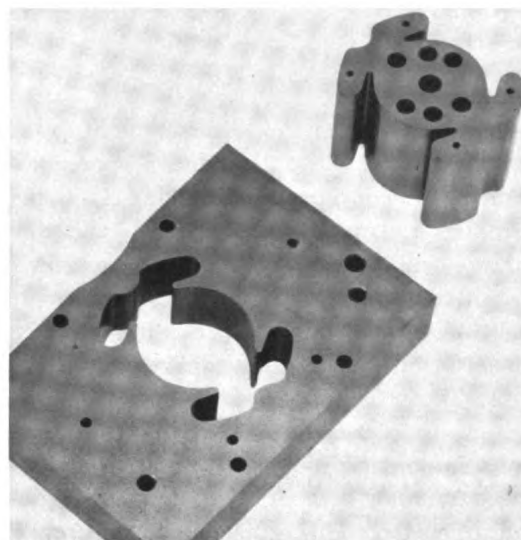


Fig. 122 — The punch and die section of this all-ground stator-rotor lamination die is a typical example of work ideally suited for Jig Grinding.

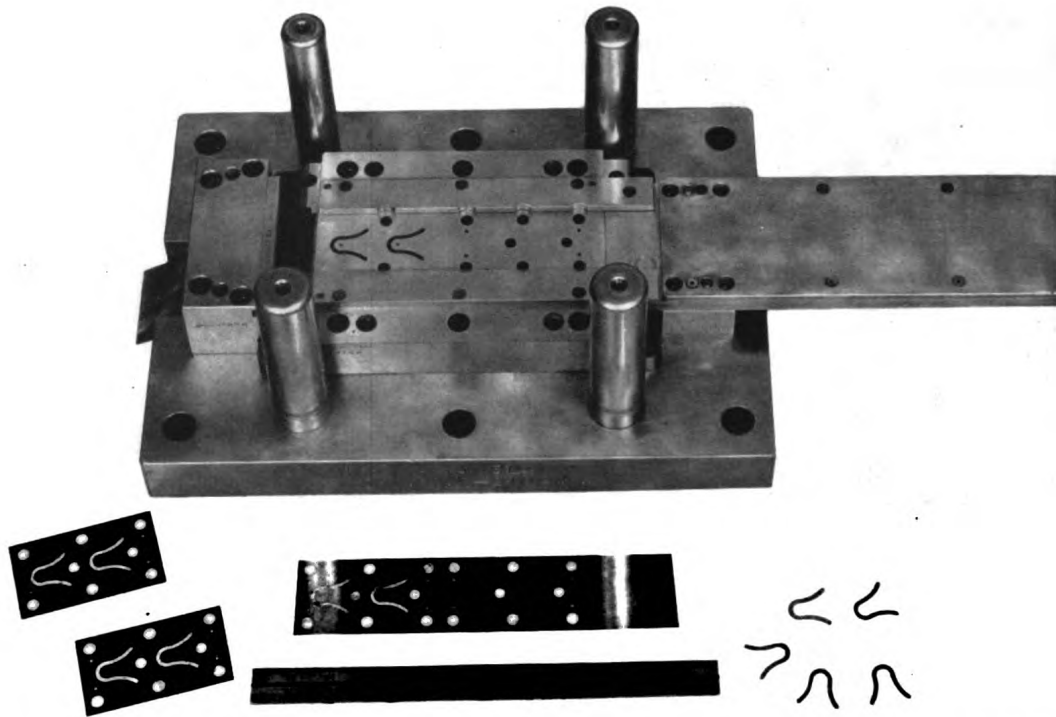


Fig. 123 — Although the die itself was made in sections, contour Jig Grinding proved to be the most efficient means for accurately establishing size and location without the blending problems encountered in other methods.

3. The ability to grind holes, and more particularly enclosed contours, eliminates the need to compromise design to the detriment of strength and performance. Also avoided is the necessity of splitting sections containing contours. These may be ground in a solid piece, with greater economy and strength.

It is by no means an overstatement to say that the advent of the Jig Grinder has revolutionized the concept of toolmaking. In many instances the unique capabilities of this machine, particularly in contour grinding, have permitted modification and improvement of tool and product design, providing a means for performing operations hitherto considered impractical.

It is, therefore, important that the principles and scope of Jig Grinding be understood by management, designer, supervisor and operator. This knowledge will reveal numerous instances in which product quality and tool accuracy can be improved, and cost and delivery time reduced.

A typical example of tool re-design influenced by the Jig Grinder is the press tool in Fig. 123. As originally designed, this tool for producing accurate blanks from thin tool steel stock was a serious compromise between practicability and available toolmaking methods of construction.



Fig. 124 — This flanged punch, impractical to grind by any other method, represents an ideal example of contour Jig Grinding.

## JIG GRINDING PRINCIPLES AND APPLICATIONS

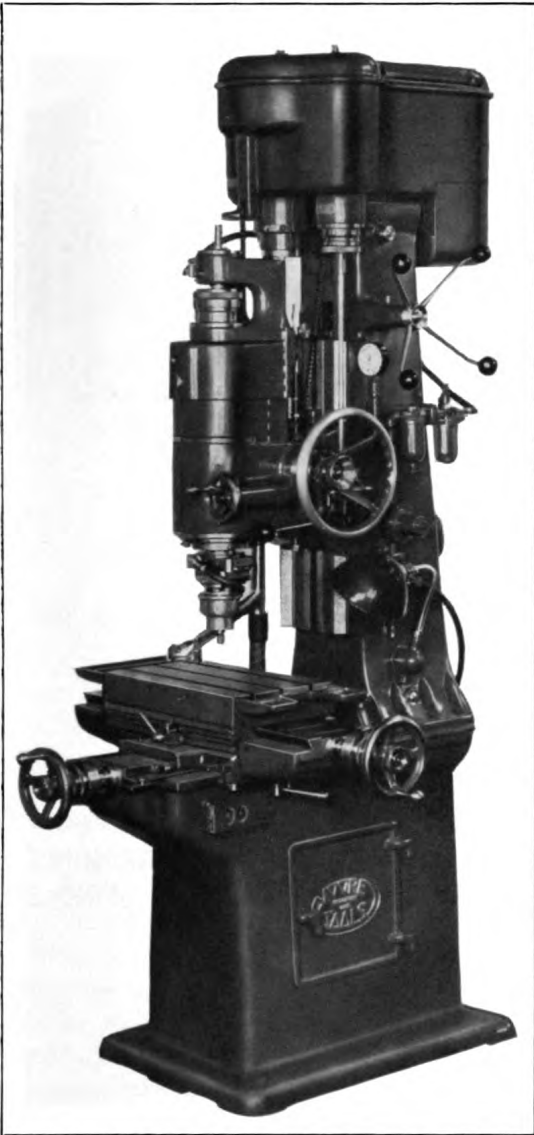


Fig. 125 — The original No. 1 Moore Jig Grinder was conceived as a means for accurately locating and sizing straight and tapered holes in hard metals. It combined rectilinear positioning with planetary grinding.

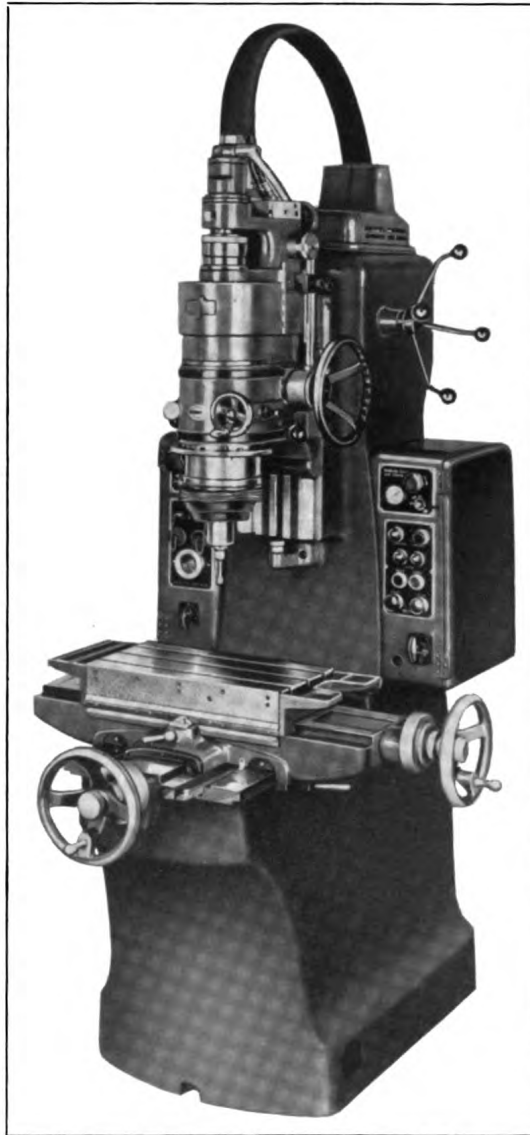


Fig. 126 — The No. 2 Moore Jig Grinder was developed around the proven principles of the original design, but incorporates features that expand its functions to include contour Jig Grinding.

The punch contour was designed as a thin-walled section to be ground linearly with a contoured wheel, and subsequently nested and fastened to the punch plate. The weakness and dubious accuracy inherent in such construction are obvious, but without a knowledge of Jig Grinding it appeared to be the best way.

The die, although sectional, presented seri-

ous problems of inaccurately relating and blending the various radii and straight sections comprising the contour.

Introduction to the Jig Grinder enabled the designer to specify a solid punch with integral flange, Fig. 124, the strongest, most accurate construction possible. Similarly, although the die was still sectioned to avoid grinding such a large perimeter with so small

a wheel, the contour was ground complete, to size and location, without blending. As a result, the punch and die were assembled without fitting, with a uniform .0005" clearance.

In this instance, the Jig Grinder aided the making of a vastly superior tool at far less cost than could have been achieved by any other method.

In order to perform the important additional operations of contour grinding, as well as to improve the efficiency of conventional hole grinding, the original machine, Fig. 125, was completely re-designed. The new development, Fig. 126, includes some interesting features resulting from the use of inter-related hydraulic, pneumatic, electrical and mechanical mechanisms.

Although the Jig Grinder is rapidly becoming a recognized *basic type* of machine tool, it is still new to many. For this reason it may be well to compare it directly to the more familiar Jig Borer, particularly since all of the measuring and positioning portions of both machines are identical, and both machines are of the vertical spindle type.

Hole grinding with the Jig Grinder is based on the familiar motion encountered in single-point boring; thus, the analogy between Jig Grinder and Jig Borer becomes even more apparent. This may be clarified if the grinding wheel is compared to a tool bit held in an outfeed boring chuck, as would be common practice in the case of the Jig Borer.

Because hole grinding must be performed with the workpiece and table in a fixed position, a planetary motion is imparted to the grinding wheel spindle as a means of controlling hole diameter. This was accomplished by vertically mounting the pneumatic turbine grinding spindle on a nominally horizontal, adjustable dovetail slide attached to the lower end of the spindle assembly, Fig. 127.

Since the axis of rotation of the main spindle is fixed by a pair of extremely accurate preloaded ball bearings, it is apparent that displacement of the axis of the grinding

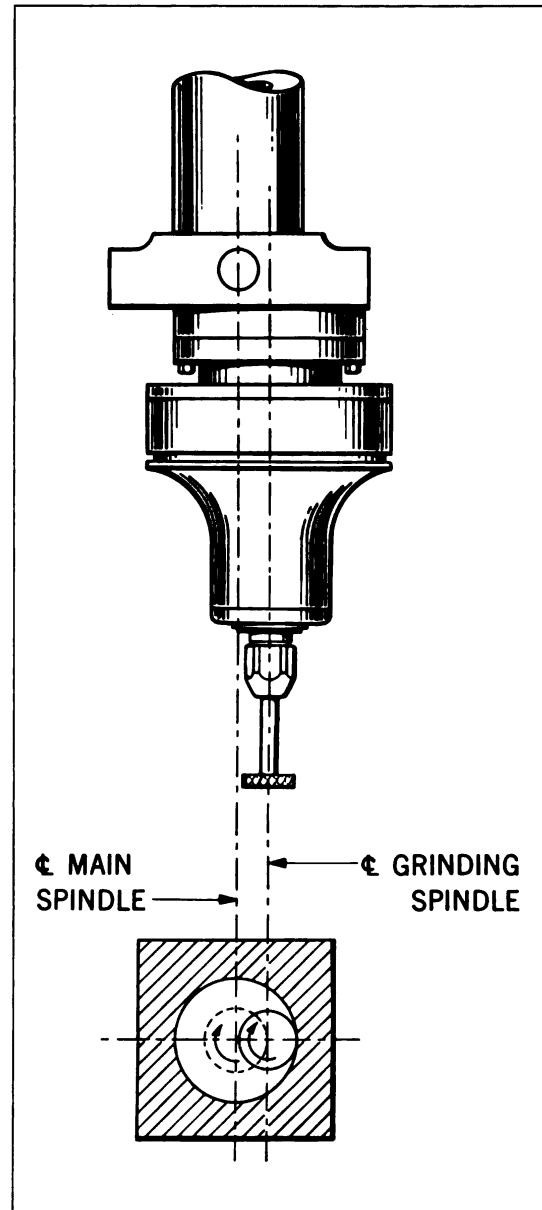


Fig. 127 — High-speed pneumatic grinding spindle adjustably offset from main spindle. Lower view shows planetary path of rotation.

spindle from that of the main spindle will result in an increase in the diameter of the hole being ground, Fig. 127, lower view.

**Where Jig Grinder Differs from Borer** — The preceding description covers what might be termed a "basic" Jig Grinder, but it neglects two considerations: The ability to outfeed

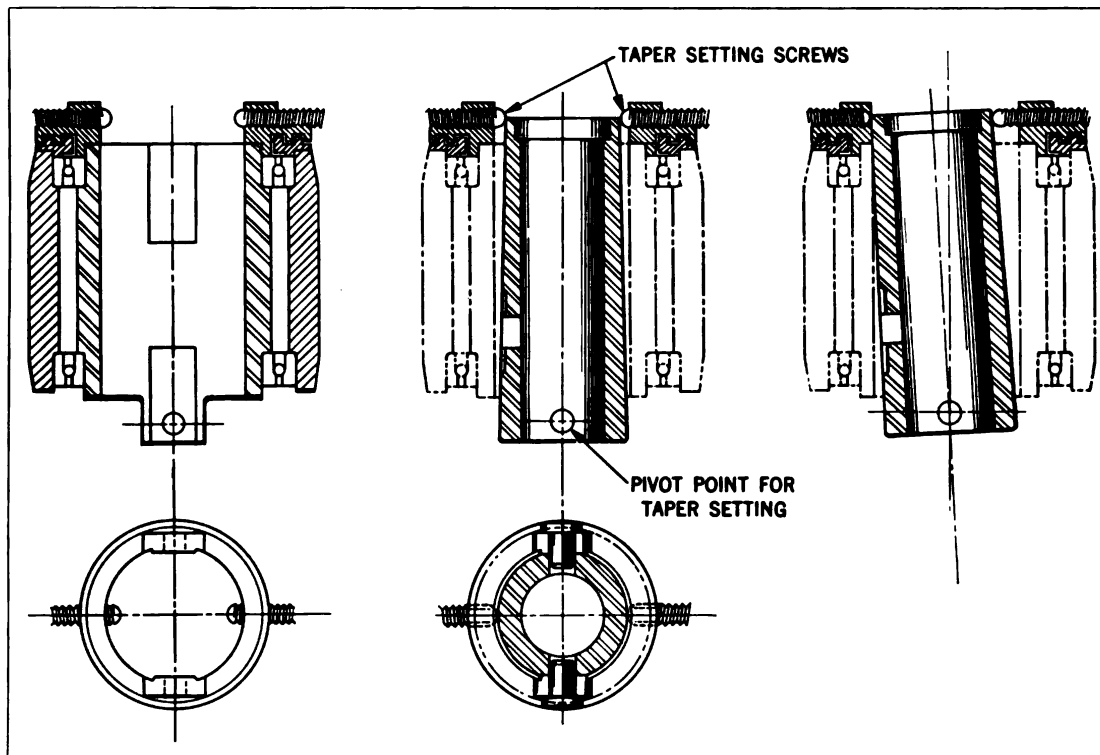


Fig. 128 — Main spindle assembly (left), inclinable guide sleeve set for straight grinding (center), and set for taper grinding (right).

the wheel accurately while grinding, and the ability to grind tapered holes. The importance of these features alone precludes the idea of converting a Jig Borer to an efficient Jig Grinder by the mere addition of a grinding spindle. Additional refinements have further sharpened the line of demarcation between the two machines.

**Taper Setting** — Because taper grinding resulting from integrating downfeed with out-feed would involve structural as well as operational complications, and would require the use of taper dressed wheels, a more straightforward solution was sought. This resulted in a spindle assembly, Fig. 128, into which an inclinable member was introduced. This inclinable vertical guide sleeve is pivoted at its lower end on a pair of diametrically opposed pivot pins projecting inward through ears on the lower end of the hollow main spindle, Fig. 128, center.

Thus, by adjustment of the taper-setting

screws, the axis of the bore of the vertical guide sleeve may be inclined at an angle to the axis of rotation of the assembly, Fig. 128, right. Likewise, this inclinable axis may be made to coincide with that of the spindle for straight grinding.

In order to transmit the reciprocating motion necessary for grinding, a vertical slide is fitted within the bore of the guide sleeve, Fig. 129. This slide is free to move axially in the bore of the sleeve and is keyed to it. The dovetail slide, previously described as carrying the offset grinding spindle, is mounted on the lower end of the vertical slide, Fig. 129.

In Fig. 129 is also shown the cone generated by the slide as it reciprocates on its inclined axis, which is rotating about the fixed, vertical axis of the spindle. By construction, the axis of the grinding spindle remains parallel to that of the vertical slide, whether the latter be set for straight grinding or inclined for taper grinding, and may be

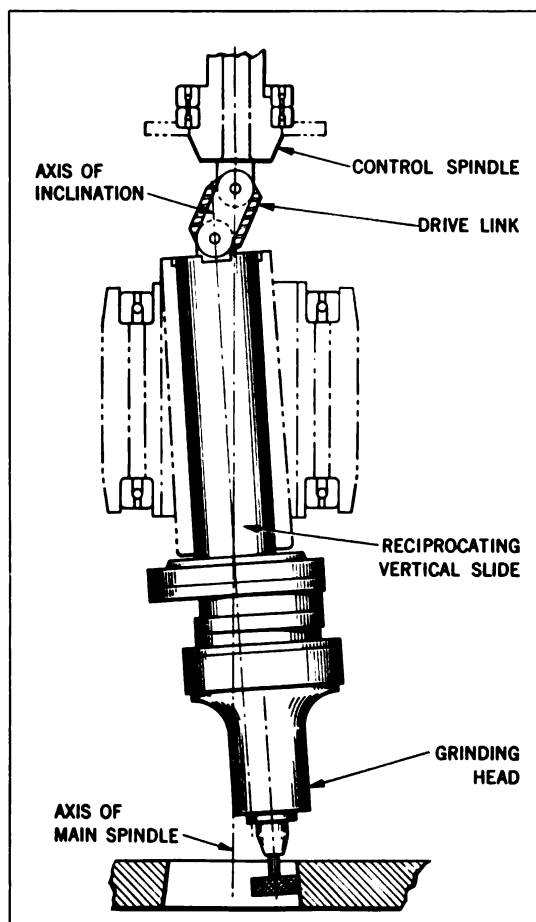


Fig. 129 — Reciprocating vertical slide mounted within inclinable guide sleeve. Main and control spindles are on a single, fixed axis.

outfed in either position, as previously described. It will be observed that, even for taper grinding, the wheel is dressed to the conventional cylindrical shape, Fig. 129.

**Vertical Feed** — Because the basic reciprocating member of the Jig Grinder is inclinable and located within the rotating spindle assembly, the conventional direct rack and pinion method of imparting vertical movement could not be employed. Consequently, it was necessary to introduce a rotating control spindle above the main spindle assembly and coaxial with it. This member could then be reciprocated together with its supporting yoke and transmit both vertical and rotary motion to the upper end of the vertical slide

through a tubular, semi-universal drive link. This construction permits the slide to be inclined at an angle to the mutual axis of the main and control spindles, Fig. 129.

To maintain alignment between the control spindle and the main spindle, and to permit vertical movement of the former, the aluminum yoke which contains the control spindle is supported on a pair of hardened steel, vertical guide rods. These rods are located at either side and to the rear of the spindle paralleling its axis, Fig. 130. The upper ends of these rods are fixed in the yoke; the lower ends are located, but free to move vertically, within hardened bushings in the main spindle housing.

At this stage of design, it was apparent that racks in the lower end of the guide rods, operating with pinions on a transverse shaft through the main spindle housing, would provide a satisfactory vertical actuating means. A handwheel on the end of the shaft serves to complete the mechanism.

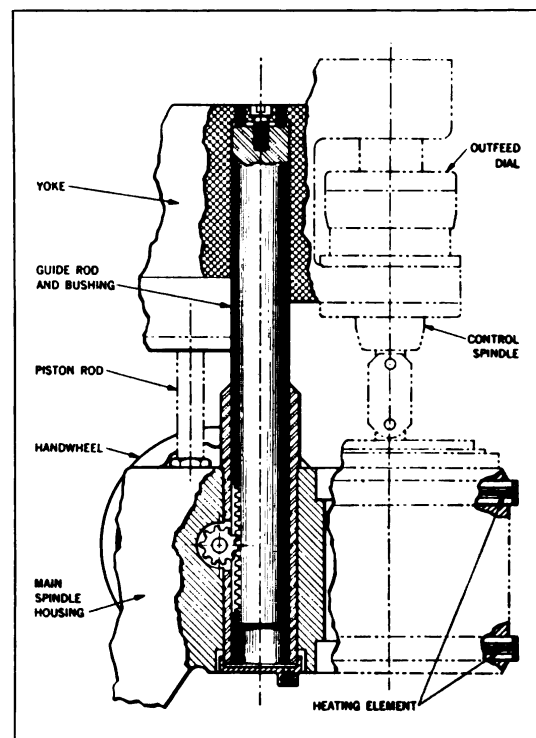


Fig. 130 — Alignment and vertical hand movement are achieved by means of guide rods.

## JIG GRINDING PRINCIPLES AND APPLICATIONS

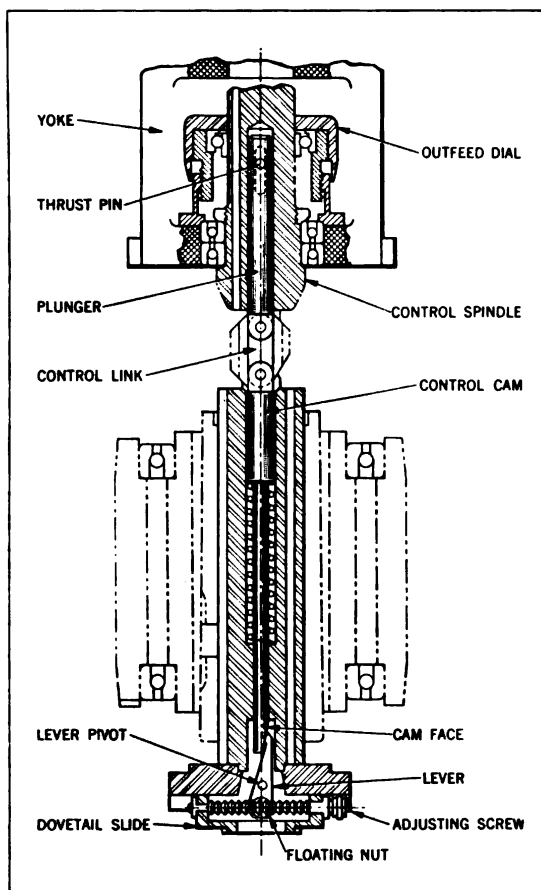


Fig. 131 — Assembly for controlling size by outfeed while grinding. Dial setting outfeed is graduated in "tenths."

**Outfeed** — Outfeed while grinding is controlled by an internally threaded, graduated dial, much like the barrel of a conventional micrometer, mounted on the non-rotating yoke outside the control spindle and concentric with it, Figs. 130 and 131. By virtue of the screw thread, rotation of this dial causes an axial movement which is transferred by an anti-friction bearing to a spring-loaded thrust rod system in the rotating control spindle and vertical slide. An inclinable link within the drive link transmits thrust, even when the slide is set for taper grinding. A cam on the lower end of this rod, working against a pivoted lever, translates this axial movement into lateral displacement of the dovetail slide carrying the grinding spindle. The dial is

calibrated in tenths of one thousandths of an inch, permitting accurate control of hole diameter while grinding, Fig. 131.

Coarse adjustment, to permit approximate positioning of the wheel in relation to the surface to be ground, is effected by means of a fine-pitch screw within the dovetail slide, accessible only when the spindle is stopped. Inasmuch as the thrust from the pivoted lever is applied against a pivoted nut on the coarse adjustment screw, it is a simple matter to spring-load and dovetail assembly against this nut. Thus, any backlash is eliminated in both the screw and lever.

**Spindle Housing Adjustment** — In order to accommodate workpieces of varying heights, the main spindle housing assembly is located in vertical double V-ways on the column face, and can be positioned within a range of 11". It is counterbalanced by a weight in the column through a roller chain and sprocket system, and may be locked in place by a clamp during operation of the machine.

This type of construction avoids excessive overhang of the vertical slide, which would magnify any slight inaccuracy in the ball bearings; yet it permits great flexibility of adjustment.

**Main Spindle Drive** — The preceding basic design features are common to both the original Jig Grinder and the new model. The remainder of the design differs significantly from that of the original and incorporates the desired additional performance features.

Two apparently irreconcilable factors created a troublesome problem in the design of the main spindle drive. It was necessary to establish the overall, fixed shipping height of the machine at about 90" in order to avoid the necessity of horizontal handling in trucks, elevators and doorways. At the same time, in keeping with capacity increases in all other respects, it was mandatory to increase the distance between the work table and the grinding wheel spindle by several inches.

Requirements of the spindle drive are that it shall provide a range of speeds from 85 to 350 rpm, transmit  $\frac{1}{4}$  hp, and permit the

spindle to be disconnected from the drive.

Any consideration of a variable-speed drive of the adjustable-pitch sheave type mounted on top of the column was quickly discouraged by the space requirement. Furthermore, experience proved that, while it is necessary to hold some relationship between main spindle speed and the size of the hole being ground, there is no sacrifice in grinding efficiency over a relatively wide speed range. A four-speed motor provided enough speed range and eliminated the complexity of a variable-speed drive.

From the standpoint of simplicity, it would have been highly desirable to mount such a motor directly on the yoke, thus eliminating power transmission problems. This was not possible, however, because such a weight addition could not be tolerated on a rapidly reciprocating member, nor could the added height be permitted. All other considerations dictated a vertical, shaft-up mounting within the upper end of the column.

The power transmission problem is to connect the shaft of the fixed motor to the control spindle, which is vertically adjustable over an 11" range and has a  $3\frac{5}{8}$ " reciprocating stroke. Consideration was given to the orthodox systems of V-belt, gear train and fixed shaft types. In each case, mechanical complexity, space requirement and lack of suitability forced a new approach. Analysis of the actual transmission requirements revealed that although the motor was rated  $\frac{1}{4}$  hp at 1,200 rpm and proportionately at 900, 600 and 450 rpm, the actual power requirements of the machine are but a fraction of that available.

**Flexible Shaft Selected for Drive** — After thorough test, a specially designed flexible shaft was chosen as the power transmission member. This solution presented several advantages: Simplicity, freedom from vibration, minimum space requirement and ample capacity.

A necessary speed reduction of 5 to 1 between the motor and control spindle, and

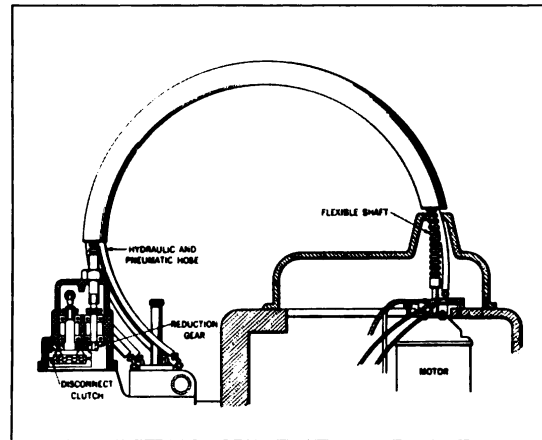


Fig. 132 — Flexible drive transmission assembly includes drive shaft, pneumatic and hydraulic lines.

the fact that a flexible shaft is better suited to transmit power under high-speed, low-torque conditions dictated that the reduction occur at the spindle end of the drive. A simple spur-gear reduction was employed. This was housed, together with a positive, tooth-type clutch, on the yoke at the upper end of the spindle. This arrangement further served to place the disconnect clutch control within reach of the operator.

As applied, the shaft is looped through a 180° arc from the motor shaft to the reduction gear housing on the yoke, Fig. 132. The height of this arc is determined by the position of the main spindle housing, so that by lowering the housing it is possible to comply with the shipping height requirement.

**Power Reciprocation** — Mechanical reciprocation of the yoke and connected member appeared impractical, due largely to the necessity for infinite rate from 0 to 120 strokes per minute, and an adjustable stroke from  $\frac{1}{4}$ " to  $3\frac{5}{8}$ ". On the other hand, the natural identification of reciprocating motion with piston stroke pointed toward utilization of compressed air, already necessary for operation of the pneumatic grinding spindle, and therefore available at 100 P.S.I. as a power source.

In its simplest form, such an application would consist of a double-ended cylinder

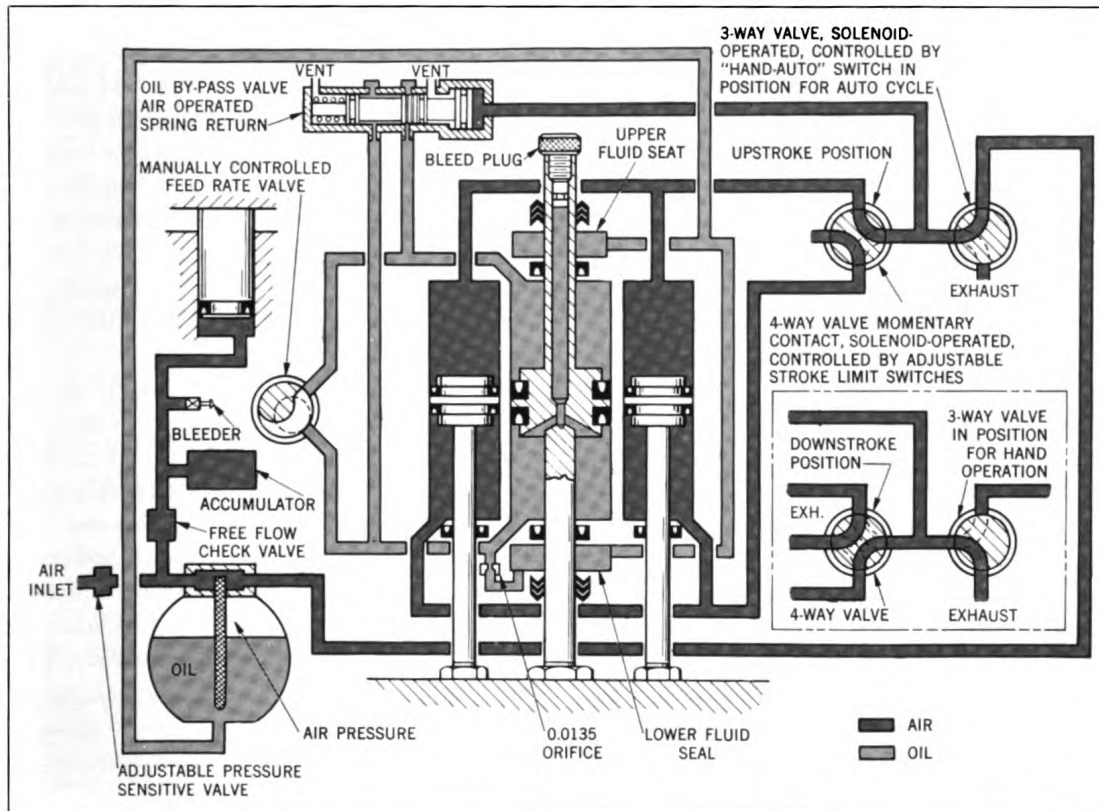


Fig. 133 — Schematic hydraulic-pneumatic circuit diagram.

mounted vertically in the yoke, with the piston rod attached to the spindle housing. Reversal of movement could be accomplished by a four-way solenoid valve which would allow pressure to be applied to either end of the cylinder while the opposite end is open to exhaust. Thus, in effect, the cylinder and yoke would reciprocate on the fixed piston, the stroke being controlled by limit switches and adjustable stops. Actually, two such cylinders were found necessary, as will be explained later. These cylinders were mounted in the yoke, behind the guide rods.

Experiment showed that operation was satisfactory in a pressure range from 70 to 85 P.S.I., controlled by a pressure regulator and gage.

**Reciprocation Control** — Although compressed air proved to be an ideal power source in most respects, its compressibility resulted in several undesirable by-products:

Non-uniform movement at slow rate of travel; excessive over-travel after reversal of solenoid valve; and difficulty of travel rate control by pressure regulation or metering of flow.

To eliminate the unfavorable characteristics of air as a source of power, while taking advantage of its general suitability, it was necessary to mount a double-ended hydraulic cylinder between the pneumatic cylinders, to act as a regulating member. Employment of a double-ended hydraulic cylinder in a closed circuit with an adjustable orifice valve, as a means of controlling air power, was not, in itself, unique. However, modifications of that system for this specific application resulted in several unusual design features.

Pressure in the air cylinders, as Fig. 133 shows, cannot cause movement of the yoke without an equivalent displacement of fluid from one end of the hydraulic cylinder to the

other through the flow-control valve. The fluid, being virtually incompressible, permits infinitely fine control of the rate of travel, by means of the adjustable orifice in the valve.

To avoid changing the travel rate setting of this valve to give unrestricted flow for hand feeding, a supplementary by-pass valve was included in the hydraulic circuit. This valve, controlled by a push button through a solenoid, makes possible instantaneous change-over from auto-feed to hand-feed by opening a direct passage from one end of the cylinder to the other.

**Compensating Fluid Seal** — Although the hydraulic circuit has been previously referred to as a closed circuit, it is only nominally so. In the final version of the design, a supplemental, pneumatically pressurized hydraulic sealing system was superimposed on the basic hydraulic control circuit, Fig. 133. This solved several problems and offered many advantages:

1. It provided a fluid seal against the cylinder piston rod seals, so that any leakage at that point could not be replaced by air.
2. A small (.0135") passage connecting the control circuit with the sealing system compensates for the volumetric change in the fluid of the otherwise closed circuit. The sealing system, being pneumatically pressurized, bleeds fluid sufficiently to maintain a constant pressure in the cylinder regardless of temperature changes.
3. The sealing system includes a large reservoir which automatically keeps the circuit full and eliminates the need for any attention to the entire assembly for a period of years.
4. Being pressurized, the entire fluid content of the circuit may be easily rid of entrapped air through a bleeder plug at the upper end of the hollow piston rod, Fig. 133.

**Pneumatic Counterbalance** — In the new design, rapid reciprocation and lack of any overhanging member from which to support the assembly precluded the use of a counterweight to balance the moving parts. At first, the idea of hollow guide rods enclosing compression springs appeared to present a possible solution. Calculation quickly showed that a four-foot length of spring would be necessary

in order to achieve a satisfactory low spring rate. This was ruled out for lack of space.

Natural similarity of the guide rod and its bushing to a piston and cylinder pointed to their use as such, in order to derive a balancing effect from compressed air. Application of this idea proved to be relatively simple. A U-cup packing was fitted to the lower end of one of the guide rods and by capping the lower end of the bushing, the chamber thus formed could be pressurized.

Inasmuch as the nominal weight of the parts to be balanced was approximately 73 pounds and the area of the guide rod end was one square inch, it was apparent that a pressure of 73 P.S.I. would support the assembly. One variable entered into the situation — the non-uniform weights of the three different grinding heads and the slot grinder, any one of which might be mounted on the slide. This factor meant that the total weight to be supported might range from 76 to 83 pounds. As previously mentioned, the pneumatic reciprocation cycle would operate without noticeable difference within a pressure range of 70 to 90 P.S.I. The identity of pressure ranges satisfactory for this purpose, and that required for counterbalancing, pointed to the use of the same regulator for both systems. Thus, slight adjustment of the regulator would perfectly balance the weight of the reciprocating parts, regardless of which of the attachments might be mounted on the slide, without affecting the power stroke.

As described, this system would serve only as a *static* counterbalance, while the function of the machine requires the dynamic type. This required a pressure-sensitive valve which would perform the following functions:

1. Admit air to the guide rod bushing as the rod moves upward, holding the pressure constant.
2. Maintain constant fixed pressure while the machine is at rest in any position.
3. Compensate for volume change as guide rod moves downward, by permitting sufficient air escape to avoid pressure change.

In its final development, this valve took the form of a self-trimming, line pressure

regulator with a compensating relief port on the output side. The resulting system provided a counterbalance so effective that no feeling of weight could be detected during hand operation of the vertical movement.

One further problem was encountered in this portion of the design. When the air supply was shut off overnight, there was no support for the vertically moving parts. To correct this, a check valve and an accumulator were added to the counterbalance system, so that the latter provided the necessary static pressure to support the assembly, despite failure of line pressure.

**Operational Controls** — Operational controls of the machine may be divided into two classifications: Automatic and manual. Because the reciprocating stroke represents the *only* fully automatic cycle of the machine, it will be discussed first.

**Power Stroke, Automatic** — The momentary-contact, solenoid-operated, four-way valve previously described as controlling this cycle is normally energized by two fixed limit switches in the main spindle housing tripped by adjustable stops attached to the yoke. This causes automatic reversal at either end of the stroke. These stops are so arranged that, by adjusting two pinion knobs operating with rack-cut rods, the stroke length may be adjusted between  $\frac{1}{4}$ " and a limit of  $3\frac{5}{8}$ " of travel. Any stroke shorter than the maximum can be positioned anywhere within the limits of travel.

**Power Stroke, Manual** — This cycle may also be manually controlled by a lever arranged to trip either of two limit switches, so connected as to cut out the auto-cycle switches. Reversal of vertical movement may be instantly and exclusively controlled by the operator. He may reverse the stroke at any point and, so long as the yoke remains within the range established by the auto-cycle limit switches, release of the self-neutralizing lever merely restores the automatic cycle. However, by holding the lever in the desired direction until the auto-cycle limit switch has been

over-ridden, the stroke will continue to its travel limit, where it will remain. To return to the auto-cycle stroke, it is only necessary to move the lever momentarily in the opposite direction, thereby causing the stroke to re-enter the zone between the limit switches.

**Hand Feed** — To use the handwheel for vertical movement, it is necessary to complete the following cycle:

1. Cut off the air supply to the pneumatic cylinders and open both ends of the two cylinders to exhaust.
2. Move the by-pass valve in the hydraulic control circuit to wide open, for free flow of the fluid.

This necessitates a three-way, solenoid-controlled valve in the line supplying air to the four-way valve, Fig. 133. Since the function of the four-way valve is to pressurize alternately the upper and lower ends of the air cylinders and simultaneously exhaust the opposite ends, it follows that one end of each cylinder is always connected to the air supply line while the opposite end is open to exhaust, Fig. 133.

The three-way valve is controlled by two push buttons on the control panel. The button marked "Hand-Feed" positions this valve so that it shuts off air to the four-way valve and opens the previously pressurized port to exhaust, thus completing the first step.

Simultaneously, pressure which has held the by-pass valve closed during power operation is released by the same three-way valve, Fig. 133. Its spring then returns it to full open position, completing the second step.

Instantaneous return to power reciprocation is provided by a push button marked "Auto-Feed." This reverses the position of the three-way valve, pressurizing the four-way valve and by-pass valve for power operation.

**Spindle Rotation, Power** — Speed selection for the four-speed motor driving the main spindle is governed by a four-position selector switch. Actual starting and stopping at any selected speed is handled by a pair of appropriately marked push buttons.

**Spindle Rotation, Hand** — The disconnect

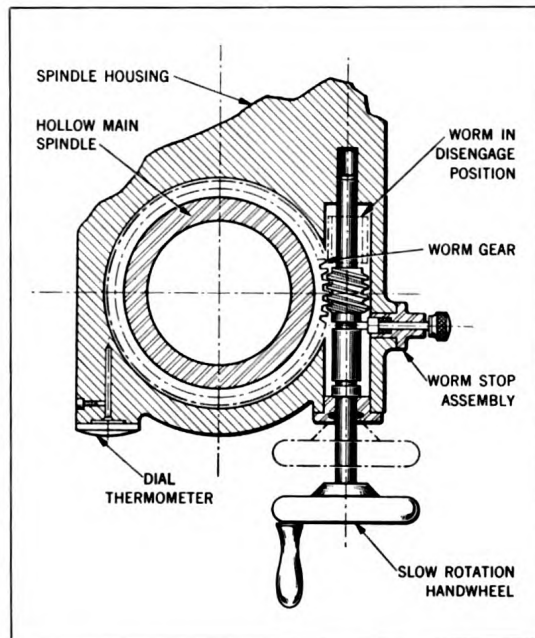


Fig. 134 — Worm and gear assembly for hand rotation of main spindle.

clutch, mounted on the yoke, is lever-operated for easy rotation of the spindle. Hand rotation for indicating and job setup may be performed by turning the aluminum guard directly below the main spindle.

Slow, accurately controlled movement for contour grinding may be made by use of a handwheel projecting from the main spindle housing, Fig. 134. This handwheel is mounted on a worm shaft, which normally is held in a neutral position by a detent plunger. The worm moves axially by release of the plunger into engagement with a worm gear on the main spindle, causing rotation of the entire spindle assembly. An electrical interlock prevents operation of the motor while the worm is engaged.

**Angular Arc Setting** — In contour grinding, it is frequently necessary to grind portions of cylindrical surfaces between accurately determined angular limits. Therefore, it must be possible to rotate the spindle assembly back and forth through a controlled arc.

The angle is determined by a ring graduated in  $5^\circ$  increments, attached to and

rotating with the main spindle, immediately below the housing. These graduations are read in degrees against a fixed vernier on the housing. To avoid the need for continuous reference to these graduations during grinding, the ring was designed with a circular slot of an inverted T shape. Adjustable stops in this slot may be positioned to control the arc of rotation, once it has been determined, against fixed stops in the housing. Thus the spindle may be rotated between positive stops without further reference to the graduations, Fig. 135.

To avoid the danger of starting the motor while the stops are in place, the following safety features have been devised: A two-piece circular guard was designed to cover the rotating parts of the assembly; without the guard in place an electrical interlock renders the motor starting switch inoperative, and the guard cannot be fitted in place until the fixed, angular stops have been removed.

**Pneumatic and Electric Spindle Drives — Grinding Spindles** — The grinding spindles, mounting on the offset slide, are of two basic types, one powered by compressed air and the other electrically. This is not as contra-

Fig. 135 — Adjustable positive stops and graduations permit control of arc of rotation of main spindle.



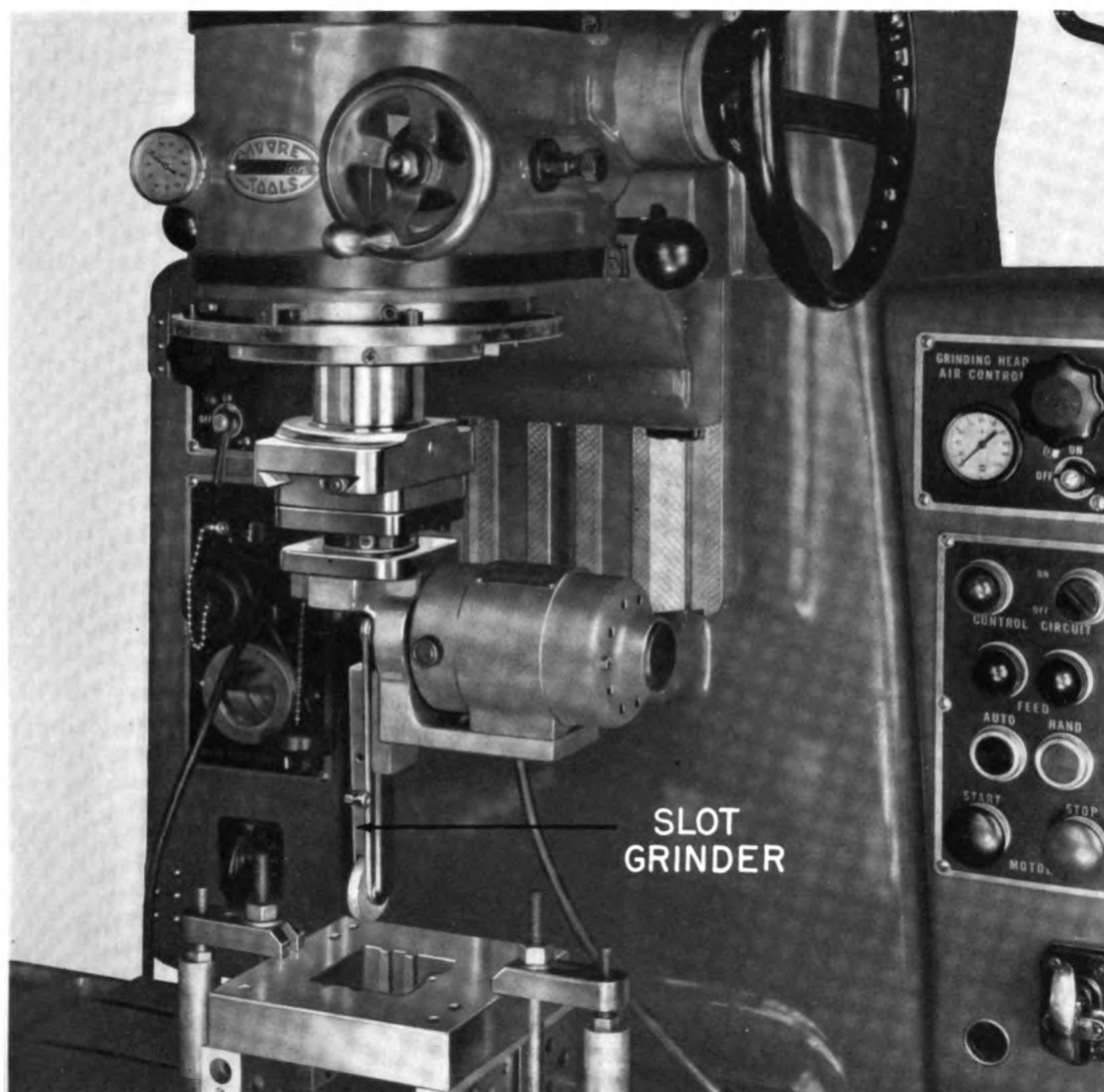


Fig. 136 — Typical contour grinding job with horizontal spindle "slot grinder" on No. 2 Moore Jig Grinder.

dictory as it might appear; different factors influenced the choice in each case.

**Vertical Spindles** — Because of the variety of hole sizes encountered in Jig Grinding, a wide range of spindle speeds is necessary. Fortunately, two factors tend to limit the extremes of wheel speed which might otherwise be required:

1. The theoretically ideal speed of 6,000 surface feet per minute for conventional abrasive wheels actually has a rather wide tolerance within which efficient grinding may be performed.

2. Experience has shown that for holes below  $\frac{3}{16}$ " diameter, a diamond-charged mandrel is more efficient than a wheel, because of the hardness of the abrasive and greater rigidity. In smaller holes, down to .015" diameter, mandrels are the only available type of abrasive tool. Since these mandrels operate best at a speed approximately one-quarter that of an equivalent wheel, extremely high spindle speeds are not necessary.

As a result, the range of required spindle speeds could be limited to 12,000 to 55,000 rpm. It would naturally seem desirable to

include this range in one self-powered spindle; unfortunately, it is characteristic that, while power is approximately proportional to speed, the requirement here is inversely proportional. Air, rather than electricity, was chosen as a power source for the vertical spindle for several reasons:

1. Speed can be easily controlled by regulation of air pressure, as contrasted with the complex system of controls and equipment necessary to accomplish this electrically.
2. Ample power, up to 1 hp, can be delivered to the spindle in a design much more compact than would be possible with an electric motor of equal power.
3. Self-cooling is inherent in pneumatic motors, a result of the refrigerating effect of volumetric expansion of the air within the motor, thus eliminating the very troublesome problem of heat.
4. Load applied, even to the stalling point, cannot possibly damage a pneumatic motor, whereas extensive damage may result from this source in a high-speed electric motor.
5. Only one connection is necessary in a pneumatic motor, the air supply, whereas, in addition to the input and exhaust lines needed for the cooling medium, electric current must be conducted to the planetarily rotating head through slip ring or similar troublesome collectors.

Three models of the vertical spindle type were necessary to cover effectively the speed range required, without excessive power loss.

For low speeds (10,000 to 14,000 rpm), a positive displacement, vane-type motor was chosen for its ability to develop power at low speed.

The range from 20,000 to 40,000 rpm, as well as that from 40,000 to 55,000 rpm, was covered by two models of the impulse-reaction turbine type, differing essentially only in rotor diameter. This design avoided the problem of friction at high speeds, which would be excessive in the displacement type, due to centrifugal loading of the sliding vanes.

Although rapid interchange of the various spindles is provided for by a quick-acting mounting on the slide, it was found that the

versatility of the 20,000 to 40,000-rpm head permitted it to be used efficiently for a range of holes from .030" to 3" in diameter. This takes care of about 90 per cent of all normal requirements.

**Horizontal Spindle** — The horizontal spindle presented an entirely different set of conditions affecting the choice of power source. Essentially, this accessory was designed to permit grinding of contours consisting of flat surfaces, either straight or angular, or relatively large radii, within the workpiece. A typical example is shown in Fig. 136.

An electric motor drive was chosen, after consideration of the following factors:

1. Due to the nature of its function, the horizontal spindle is never rotated through an arc of more than 359°; thus a conductor may be directly connected from power source to motor.
2. With the motor mounted horizontally above the spindle, a belt drive permits speed increase, from motor to spindle, by a ratio of pulley diameters, and with a 1½" diameter wheel, a standard 18,000-rpm motor could be used.
3. Heat in this type of motor is slight. It is dissipated by an integral fan in such a direction that no heat reaches the machine or workpiece.

**Stability Control** — Because of the extreme operational accuracy requirement of this type of machine, the problem of dimensional stability becomes extremely important. Common sources of instability include:

1. Deflection of structure resulting from stresses set up during operation.
2. Movement of any member by clamping pressure preparatory to operation.
3. Thermal expansion.

The first two sources posed no problem. Because of the relative massiveness of the machine members and the extremely light stresses during operation, elastic deflections are negligible. Use of the reed-type, non-influencing clamp for locking work table and a constant-pressure clamp for locking the main spindle housing to the column precluded clamping error.

Thermal expansion proved to be the most difficult condition to correct. Although atmos-

## JIG GRINDING PRINCIPLES AND APPLICATIONS

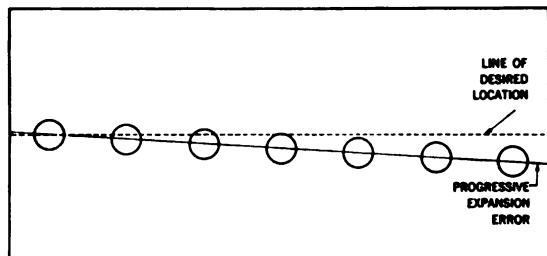


Fig. 137 — Characteristic of locational error resulting from uncontrolled spindle warm-up movement.

pheric temperature can be controlled by air conditioning, difficulties arose from the many sources of temperature variation within the machine. In the Jig Grinder this results in two highly undesirable phenomena:

1. Change in the preload of ball bearings.
2. Errors in workpiece resulting from expansion and contraction of location control members.

Location of the pneumatic cylinders on either side of the hydraulic cylinders in the yoke — in addition to avoiding a mechanical stress problem — provided an almost perfect temperature compensation condition. While fluid friction caused a slight rise in temperature in the hydraulic portion of the assembly, the cooling effect of expanding air in the adjacent cylinders canceled this and served to maintain a uniform operating temperature of 70° F.

Unfortunately, the 12° rise resulting from rotation of the hollow main spindle in its

preloaded ball bearings was immediately apparent in locational errors in the work, Fig. 137. This heat caused an expansion of the main spindle housing from its locating face on the column. This phase of the problem required a design modification in two respects. Instead of conventional iron castings, the main spindle housing is cast from a special 36% nickel iron, having a coefficient of thermal expansion approximately one-fourth that of gray iron.

To further stabilize this member, a heating element is located in the casting, adjacent to the bearings. This heating element develops substantially the same B.T.U. value as do the bearings. It is so connected to the motor control circuit that when the motor is running the heater is off, and vice versa; thus the housing is maintained at operating temperature at all times.

In the high-speed, vertical grinding spindles, temperature rise introduced the problem of variable ball-bearing preload. This was overcome by use of compression springs as a preloading means; thus, over the short range of dimensional change encountered, the axial load remained virtually constant.

Each of the preceding constructional features is vitally important in the accuracy and efficiency of machine performance. Familiarity with these points will contribute much to comprehension of the Jig Grinding practices discussed in the next two chapters.



*Jig Grinding Holes.*

## JIG GRINDING HOLES

THE JIG GRINDER has been described as performing the same functions in hardened material as does the Jig Borer in unhardened. This is correct only insofar as the location of cylindrical holes is concerned, but fails to include the Jig Grinder's ability to generate tapers and contours. These additional functions, as well as differences in working conditions, impose somewhat more exacting requirements in each of the Jig Grinding steps than generally are encountered in Jig Boring.

**Setting Up the Workpiece** — Everything said in Chapter 7 about setting up the workpiece for Jig Boring is equally applicable to Jig Grinding — plus certain additional considerations.

Jig Grinding, as a finishing operation after machining of the same location and subsequent hardening, presents a more exacting orientation problem, both in setup and dimensional pickup. Here is the reason. Where two or more locations must be ground, and assuming a minimum of stock left for grinding, a certain amount of "juggling" is necessary to insure "cleaning up" of all surfaces within dimensional limits. While in the case of simpler jobs, the setup methods described for Jig Boring are equally adaptable to Jig Grinding, workpieces having several locations to be ground often benefit from the use of a rotary table as a means of angular orientation in averaging out errors from previous machining and hardening distortion. In this application the rotary table is used as a setup tool and need not be used for angular spacing.

Work need not be clamped or held so tightly for Jig Grinding as for Jig Boring, since the pressure tending to shift the piece is so much less. Therefore, care should be used to snug down on clamp nuts *only enough* to prevent displacement during grinding and thus avoid distortion of the workpiece.

It is often convenient to be able to gage the bottom of a hole, and the work should be set high enough for this on supports or parallels. In most cases the 3" dimension of the parallel setup blocks is adequate.

**Dimensional Pickup** — As in the case of Jig Boring, after geometric orientation of the workpiece to machine travel and averaging of any errors, its relationship to the measuring system and spindle axis must be established. Mechanically the same methods are employed, i.e., the straightedge, edge-finder and indicator.

In effect, the dimensional pickup of work for Jig Grinding is a matter of deciding just where to locate the piece in the coordinate locating system of the machine, so that all existing errors can be corrected in grinding to size. This is done by setting the scales and dials to a reference represented by the average determined by picking up most, if not all, of the locations to be ground. In practice, this dimensional orientation is usually combined with angular or geometric orientation and is performed simultaneously, Fig. 138.

This step of "mapping the campaign" is extremely important. Failure to take some of



*Fig. 138 — Alignment and pickup of previously machined and hardened work are often accomplished simultaneously on the Jig Grinder.*

the factors into account may result in the operator's unhappy discovery that the last hole will not "clean up." The factors to keep in mind during this step include:

1. Favor the existing location of very small holes in relation to larger holes, since it is more difficult to move the location of the former. Also, there generally is less stock left in small holes.
2. Even where edges of the workpiece have been ground, it occasionally pays to orient the piece to favor the holes. In this case the edge can be re-ground in relation to the Jig Ground holes, if necessary.
3. In orienting contours, favor the existing location of sections which present the more troublesome grinding problems.
4. All orientation is directly related to the amount of stock left for grinding. A quick check on the existing size of each hole or contour (page 145) is often a worthwhile precaution, particularly in the case of work having numerous holes or complex contours.

## JIG GRINDING HOLES

Hole grinding requires a combination of three motions: The high-speed rotation of the grinding wheel held in the grinding head; slow, planetary rotation of this grinding head axis around the main spindle axis; and a vertical, reciprocating movement of this entire planetary action through a range determined by the length of the hole to be ground.

Choice and control of wheel speed is described on page 131. Main spindle speed (page 119) is controlled by a selector switch on the left-hand control panel. The highest speed is used for the smallest holes.

The reciprocating stroke can be manually operated by means of the downfeed hand-wheel, or automatically cycled between limits set by the stroke adjusting knobs, Fig. 139. The speed of reciprocation is governed by the feed valve, Fig. 139.

It is good practice to set the positive depth stop, Fig. 140, to limit the travel so that the wheel face extends just through the hole and clears any obstructions below. The stroke adjusting knob is then set to reverse the stroke automatically just above this point, or so that



Fig. 139 — Rate of vertical feed is controlled by valve knob, while length of stroke is set by knobs that position upper and lower limits.

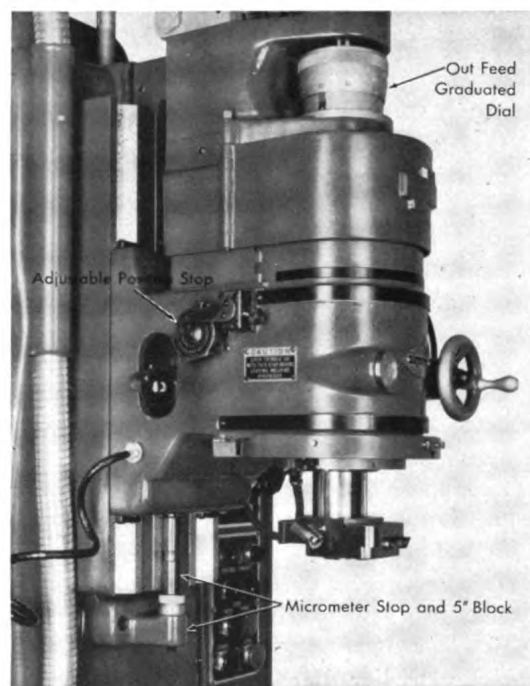


Fig. 140 — Positive depth stop facilitates grinding shoulders and counterbores to required depth and eliminates danger of over-travel.

the wheel does not come entirely out of the hole. In this way accidental over-travel will not result in damage. The upper-stroke limiting knob is set so that the wheel does not come clear of the top of the hole. This helps to avoid bellmouth.

To improve finish, speed up the reciprocating stroke for the last few passes and take the last pass at a very slow rate.

Plunge grinding (see page 129) is the most practical method of roughing. It is virtually the only efficient means to remove stock in the abrasive-resistant steels, such as high-carbon, high-chrome types. Feed for plunge grinding should be controlled by hand, so that the rate can be sensitively controlled to grind freely without glazing the wheel. Crowding the feed results in excessive wheel breakdown and taper in the hole, while too slow a feed causes the wheel to glaze. The effect of glazing can be corrected by dressing the bottom face and corner of the wheel with carborundum without altering diameter.

Holes larger than  $\frac{1}{4}$ " diameter are most efficiently ground with abrasive wheels. Since carbide burrs are occasionally suggested as an alternative, the following points should serve to clarify this controversial issue:

1. Carbide burrs must be accurately ground on the teeth, from the shank. Otherwise, they are very inefficient, because only a few "high" teeth will contact the work.
2. Since these tools represent nominal sizes and cannot be changed by diamond-dressing as can wheels, ordinary tool work would necessitate keeping a fairly large inventory in order to have a suitable size available for the variety of holes normally encountered.
3. In comparative tests on Jig Grinders, there does not appear to be any significant advantage to the burr, either in removing stock or achieving surface finish.
4. The Jig Grinder does not necessarily function efficiently with tools which may have worked well on an internal grinder.

Holes smaller than  $\frac{1}{4}$ " may be most efficiently ground with diamond-charged mandrels (see page 134).

Holes larger than those within the normal

range of the machine can be ground by use of the extension plate, Fig. 141. This accessory increases spacing between the grinding spindle axis and main spindle axis, thus permitting the grinding of holes up to 9" in diameter.

Stock removal with the conventional abrasive wheel, in general, can be accomplished by two methods, each of which has its own advantages. Frequently both can be effectively employed in the same hole:

1. *Outfeed grinding* is similar to the usual practice in internal grinding in which the wheel is fed radially into the work a few "tenths" at a time, cutting with the periphery of the wheel. This technique is generally used where there is but a small amount of stock to be removed and where the highest finish as well as accuracy in sizing is required.

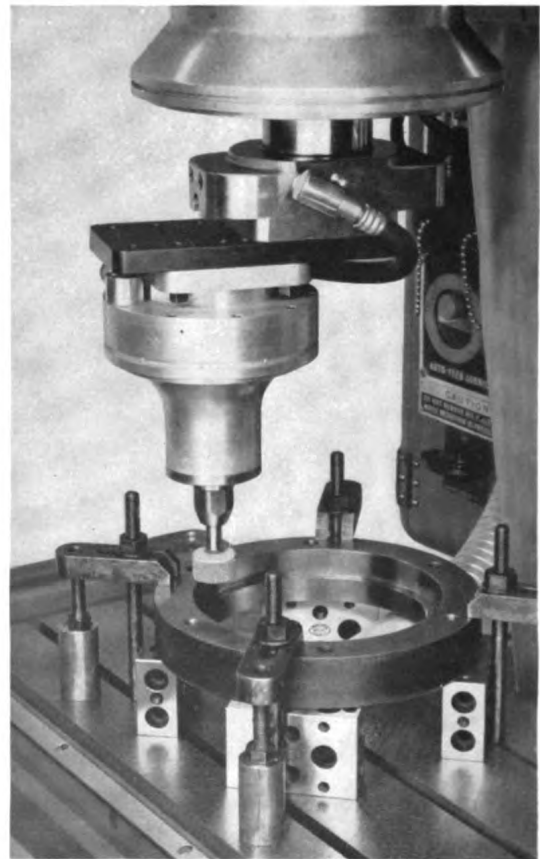


Fig. 141 — Grinding bore and shoulder of a large compound die shedder, using extension plate to increase normal diametral range of the Jig Grinder.

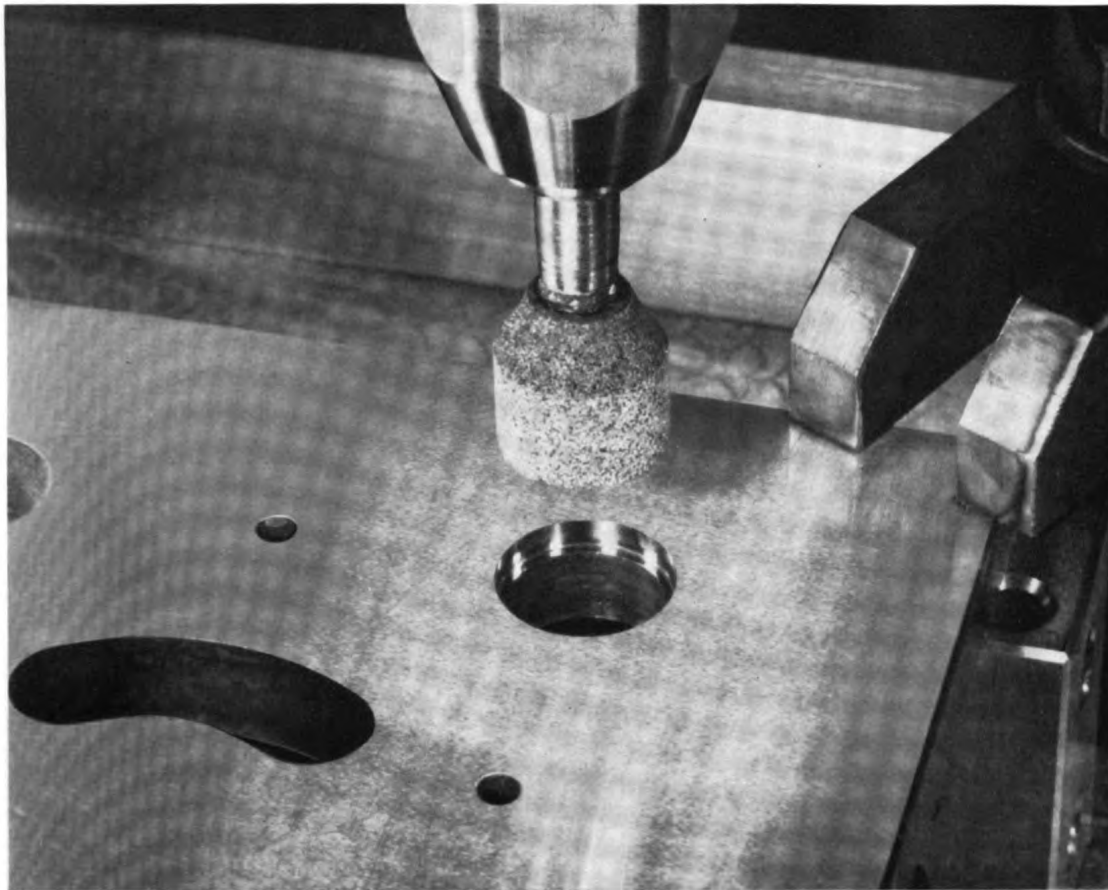


Fig. 142 — Plunge grinding to increase diameter of a hole by  $\frac{1}{16}$ " in one cut, using the 1 hp grinding head and a  $\frac{3}{8}$ " shank diameter wheel.

2. *Plunge grinding*, in contrast to outfeed grinding, utilizes the grinding wheel in exactly the same way a boring tool is used, i.e., setting it radially to cut the desired diameter and feeding it directly into the stock axially, thus cutting with the bottom edge of the wheel, Fig. 142. Stock can be removed at an amazingly fast rate with this method; for example, a 1" hole can be opened up by  $\frac{1}{16}$ " in a single pass at a rate of approximately five minutes per inch of work-piece thickness.

By combining the two methods — roughing to within a thousandth or so by plunge grinding and sizing by outfeed grinding — maximum efficiency can be attained, together with high accuracy.

**Wheel Choice** — Suitable wheel choice is the keynote to satisfactory grinding performance. Attempting to adopt wheels recommended for

an internal grinder to the Jig Grinder can easily reduce its efficiency by at least 50 per cent.

To eliminate improper wheel choice, Moore conducts a continuous research program in its own toolroom with a battery of seven machines. It also makes periodic surveys among hundreds of Jig Grinder users throughout the world. The result of this effort is incorporated in a chart showing the wheel best suited for various Jig Grinding operations on all materials ordinarily encountered.

Because many of these wheels are specially developed and are mounted on accurately ground, stainless steel mandrels, an inventory of all wheels listed on this chart is maintained for user convenience.

It is always advisable to select a shank or mandrel length proportionate to the depth

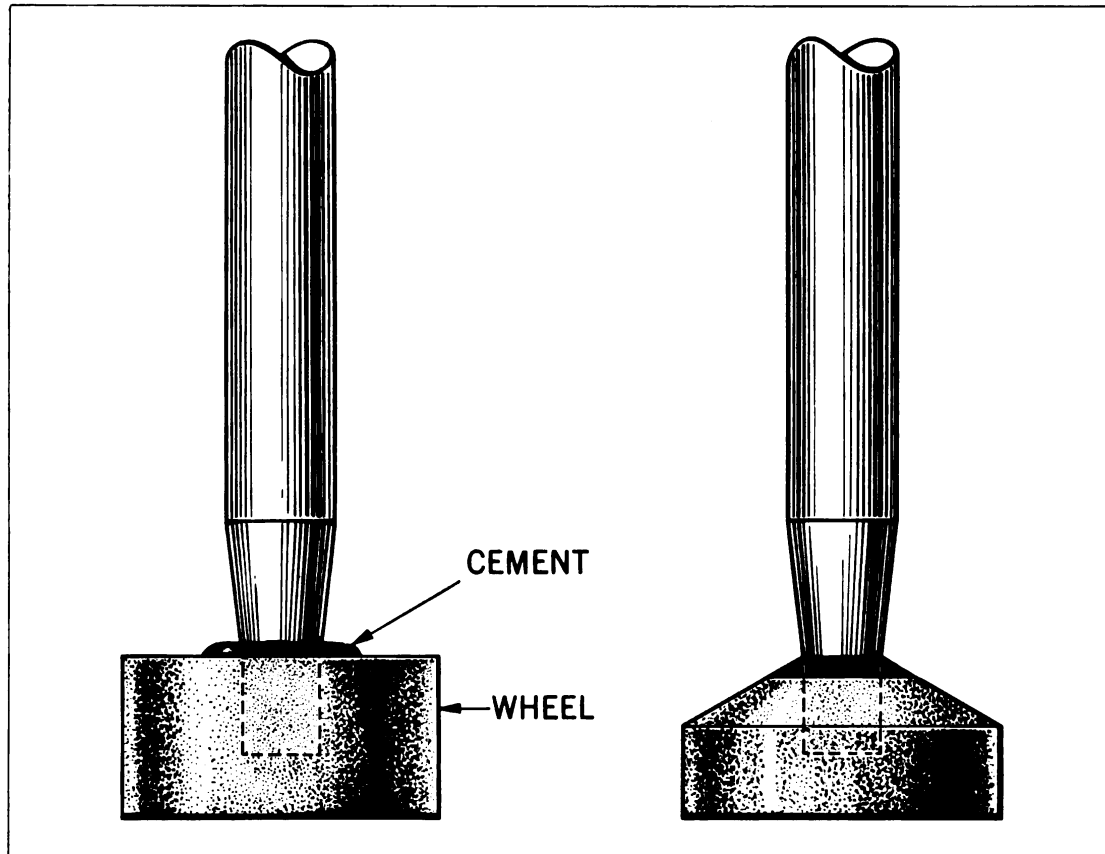


Fig. 143 — Wheel balance, attained by proper dressing, contributes much to finish and size control.

of the hole to be ground. In this way the wheel will be rigidly supported as close as possible to the grinding spindle nose. Frequently it pays to cut down an unnecessarily long shank with a hacksaw to attain this condition.

Wheel diameter should be approximately three-fourths that of the hole, except in the case of large holes where this ratio must be reduced.

**Wheel Dressing** — Equal in importance to wheel selection is the technique of dressing or truing the wheel. An improperly dressed wheel will produce the following undesirable conditions:

1. Poor finish on the surface being ground.
2. Out-of-round holes.
3. Unintentional taper or bellmouth.
4. Locational errors.
5. Surface burns.

In order to avoid these difficulties, and be-

cause it requires but a minute or two longer to properly dress a wheel, it is desirable that the following technique become a working habit:

1. Running the wheel at a reduced speed, dress the bottom face and top surface, including any cement around the shank, Fig. 143, with a carborundum stick, held by hand.
2. Before increasing speed, dress the diameter clean, using a *sharp* diamond, Fig. 144.
3. Repeat steps 1 and 2 with the wheel running at operating speed.
4. Relieve the upper portion of the diameter a few thousandths, leaving approximately  $\frac{1}{4}$ " of cutting face, Fig. 145.
5. For grinding a shoulder or bottomed hole, concave the bottom face of the wheel slightly with a carborundum stick, Fig. 146.

This procedure will develop the best cutting characteristics of the wheel. During outfeed or wipe grinding (see page 128), only the diame-

## JIG GRINDING HOLES

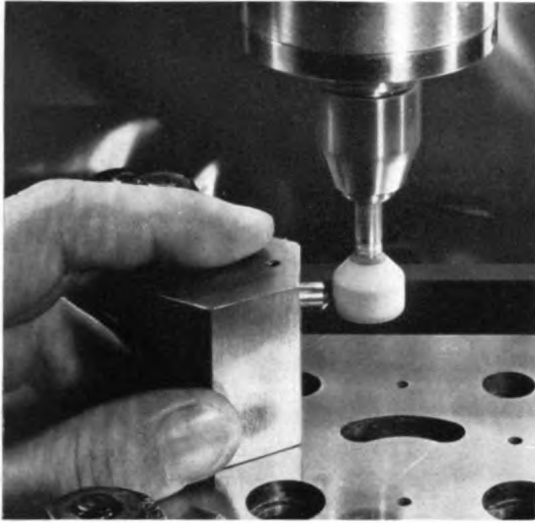


Fig. 144 — The hand-held, diamond wheel-dressing tool is convenient and effective.

ter need be re-dressed periodically. In plunge or chop grinding (see page 129), re-dressing also requires the bottom surface to be cleaned with the carborundum stick.

By painting the hole with layout blue, a freshly re-dressed wheel can be outfed until it just scratches the blue, at which point the graduations on the outfeed dial can again be related to hole diameter. Before grinding, remove the blue with a pipe cleaner dipped in acetone to avoid loading the wheel.

**Wheel Speed** — The necessary relationship of wheel speed and size to hole size makes it necessary to have a range of grinding spindle speeds available. The three grinding heads, Fig. 147, are suitable for a wide range of hole sizes. The speed of each head may be varied by adjusting the pressure regulator control-

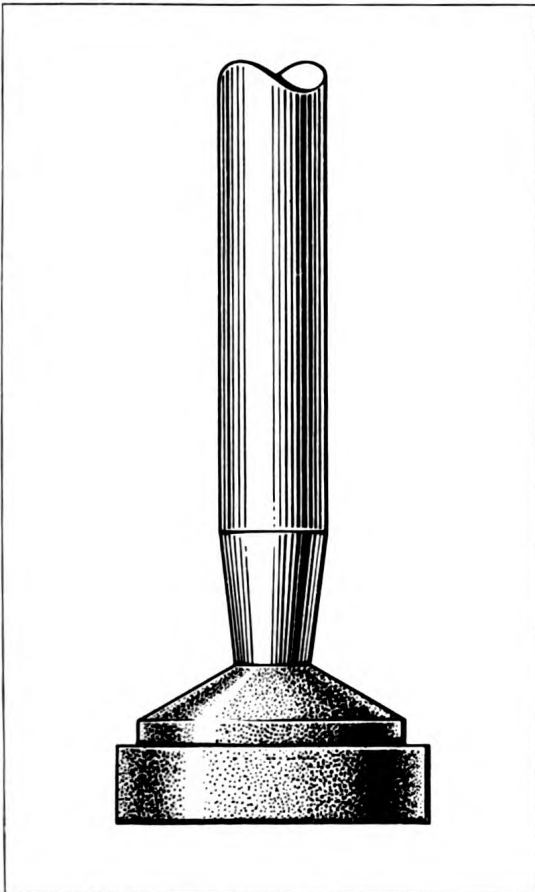


Fig. 145 — Full-face width of wheel should be reduced to avoid excessive side pressure during grinding.

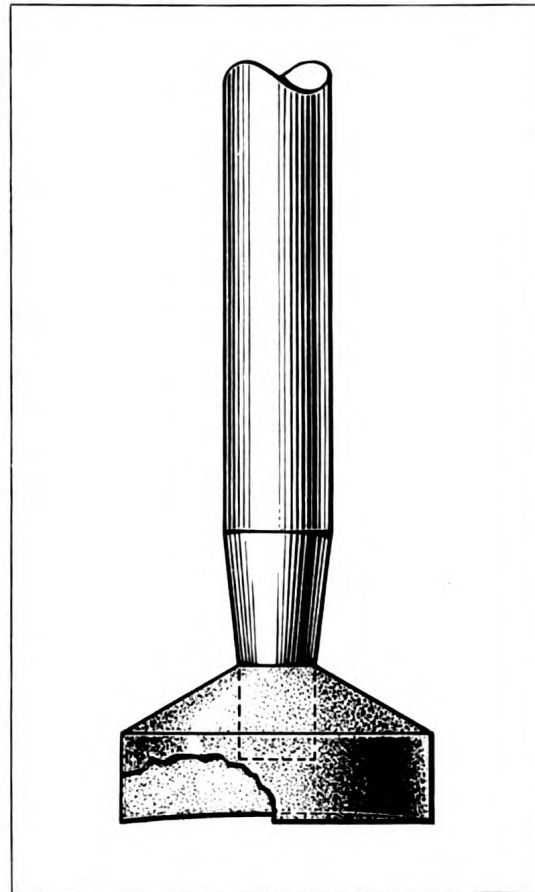


Fig. 146 — Concave bottom surface of wheel minimizes burning during bottoming.

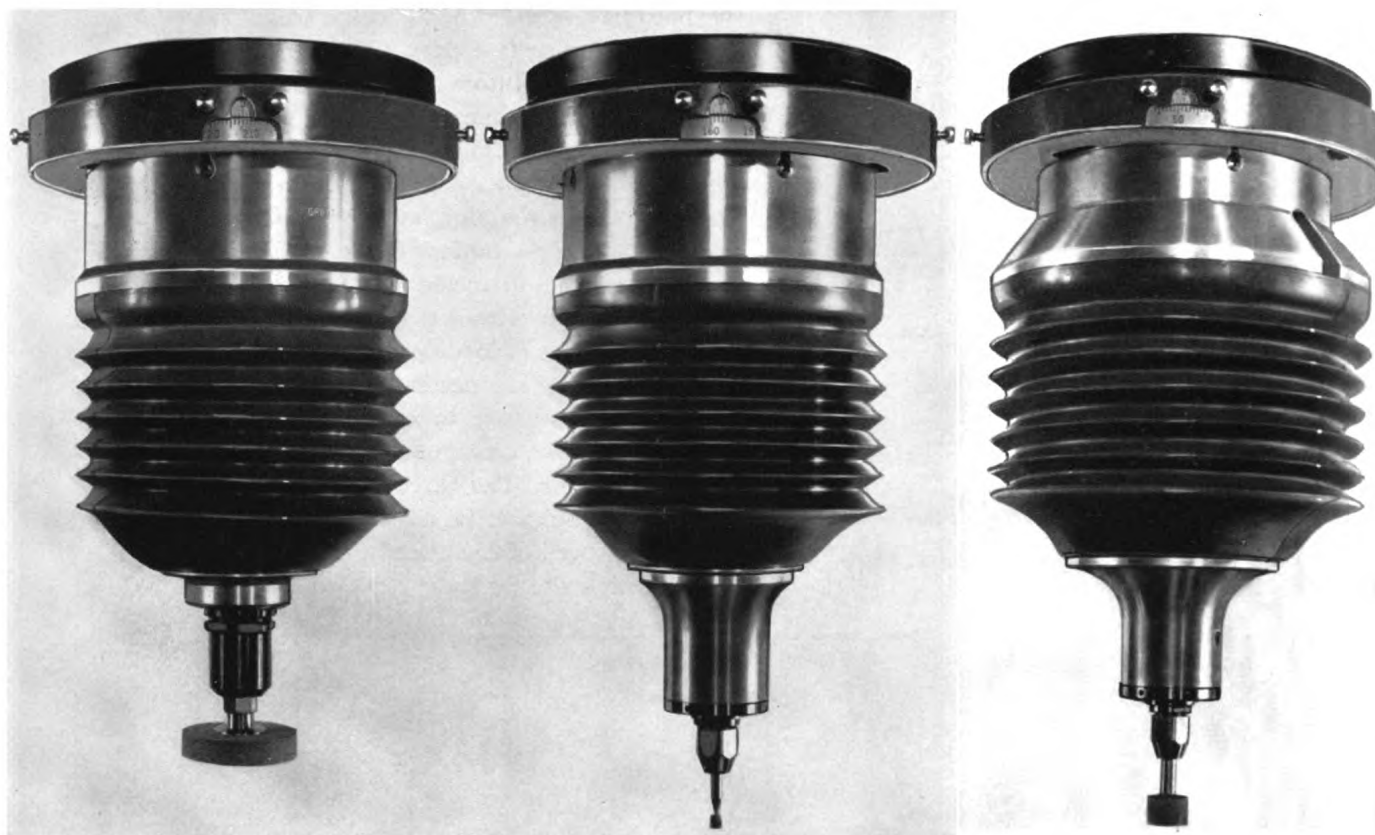


Fig. 147 —  $\frac{1}{3}$  hp Slow-Speed Air Head — Speeds: 12,000 to 15,000 rpm. Wheels Unmounted:  $\frac{3}{8}$ " hole. Wheel Diameter:  $1\frac{1}{2}$ ", 2" and  $2\frac{1}{2}$ ". Grinds Holes:  $2\frac{1}{2}$ " to 5" dia. Maximum Depth:  $3\frac{3}{4}$ ".

1 hp 1950 Design Standard Air Head — Speeds: 15,000 to 40,000 rpm. Wheels Mounted:  $\frac{3}{8}$ ",  $\frac{1}{4}$ " and  $\frac{1}{8}$ " shanks. Wheel Diameter:  $\frac{1}{4}$ " to  $1\frac{1}{2}$ ". Grinds Holes:  $\frac{1}{16}$ " to  $3\frac{1}{2}$ ". Maximum Depth:  $3\frac{3}{4}$ " on holes over  $\frac{3}{4}$ " diameter.

$\frac{1}{4}$  hp High-Speed Air Head — Speeds: 35,000 to 60,000 rpm. Wheels Mounted:  $\frac{1}{4}$ " and  $\frac{1}{8}$ " shanks. Wheel Diameter:  $\frac{1}{8}$ " to  $\frac{3}{4}$ ". Diamond-charged Mandrels to Suit. Grinds Holes:  $\frac{1}{16}$ " to  $\frac{3}{4}$ ". Maximum Depth: Six times hole diameter.

ling its air supply. The relation of pressure to rpm is shown on a chart, Fig. 148.

**Shouldered Holes** — Wheel size should be small enough so that the back of the wheel will clear, Fig. 149, in order to avoid scuffing

during shoulder grinding. It will be noted in the same illustration that the wheel has been slightly concaved on the bottom by a carborundum stick.

Depth is controlled in this operation by the

APPROXIMATE SPEEDS IN TERMS OF PRESSURE P.S.I.

	P.S.I.	30	40	50	60	70	80	90	100
I H.P. STANDARD AIR HEAD	R. P. M.	16,000	19,400	23,000	26,400	29,700	33,200	36,600	40,000
$\frac{1}{4}$ H.P. HIGH-SPEED AIR HEAD	R. P. M.	29,000	36,000	41,500	46,000	48,000	51,300	56,200	60,000
$\frac{1}{3}$ H.P. SLOW-SPEED AIR HEAD	R. P. M.	5,500	8,000	10,000	11,000	12,000	13,000	14,000	15,000

Fig. 148 — This chart provides a guide in converting pressure gage values to rpm of grinding spindle.

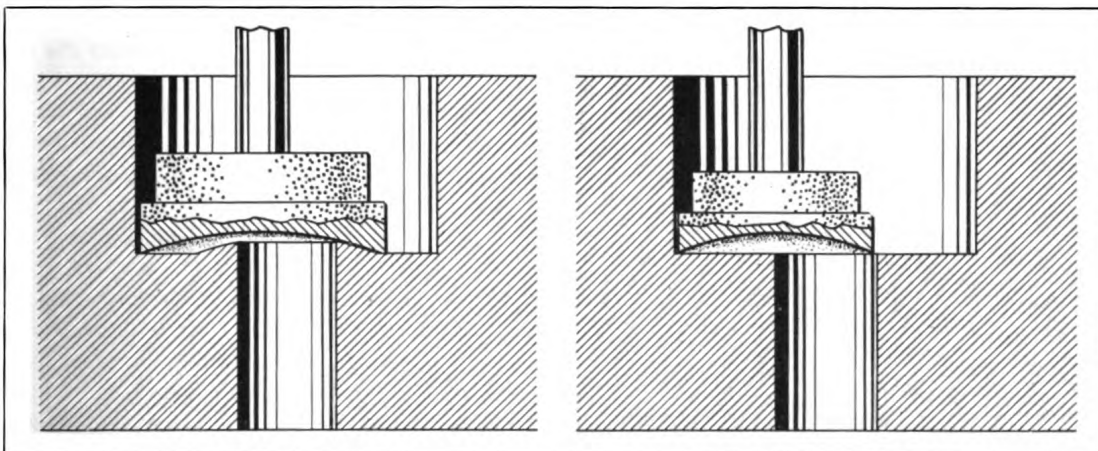


Fig. 149 — If wheel is too large (left) it will not grind a flat surface. It should be small enough to clear opposite side of hole (right).

positive stop, which is set so that the wheel just brushes the surface of the shoulder. The diameter of the hole is ground conventionally, reciprocating the wheel by hand and simultaneously feeding down to clean the shoulder by backing off on depth stop screw until the surface "cleans," or a desired depth is reached.

**Taper Hole Grinding** — The Jig Grinder can be set to grind taper in either direction, as indicated by the taper-setting plate, Fig. 150. Adjustment is made by backing off one and advancing the other of the opposing adjustment screws, Fig. 128.

Ordinarily the setting is sufficiently accurate as read in degrees on the taper-setting plate. However, when a precise angular set-

ting is required, it is advisable to transpose the information into thousandths taper per inch. Using an indicator against a square or angle iron, the setting can be made directly in these terms. The required taper is read on the indicator, through one inch of vertical movement as read on the downfeed dial.

Reversal of this procedure, or adjusting the taper-setting screws to a zero change of indicator reading during vertical movement, provides an accurate means of re-setting the machine for straight grinding.

Caution should be observed in tightening the adjusting screws in these operations. Set up too tightly, they will bind vertical movement; left too loose, they can easily cause the machine to grind out-of-round.

The actual technique of taper grinding falls into three classifications:

1. To grind taper throughout the length of a hole, set the taper, dress the wheel and then, with the wheel stopped, carefully enter it into the hole. Since it will first make contact at the bottom of the hole, be sure that it is retracted enough to clear this point. Then outfeed gradually, spinning the wheel by hand until it makes brushing contact with the bottom corner of the hole; then back off about .002" on the outfeed dial before starting the spindle. Proceed to grind as with a straight hole, Fig. 151, gradually out-feeding as the hole progressively cleans up to the top, and the required size is attained.

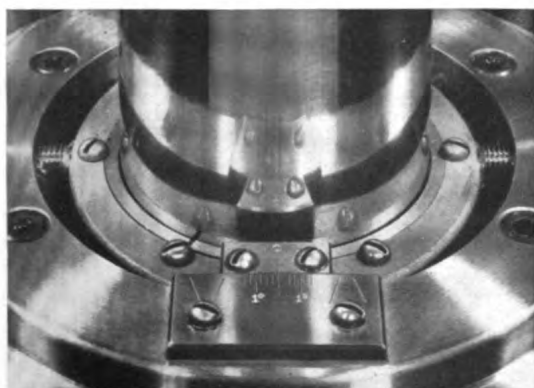


Fig. 150 — Angle of taper is read directly on the taper-setting plate.

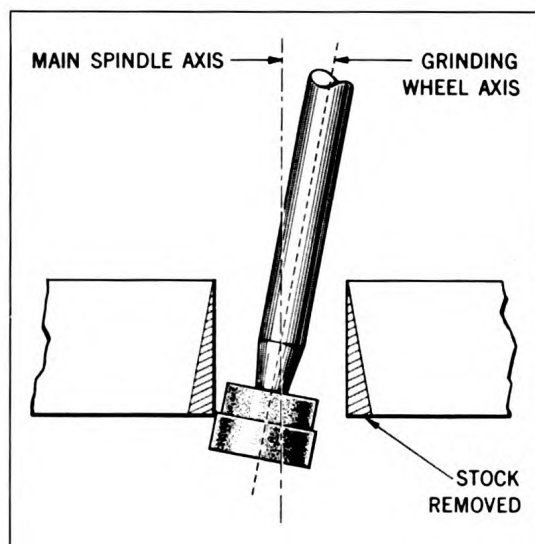


Fig. 151 — Greatest stock removal in tapering a straight hole occurs at bottom.

2. When the hole must be cylindrical for a portion of its length, below which it must have draft or taper, Fig. 152, two methods may be employed. The most common involves first grinding the hole straight and to size. The taper setting is then made and, proceeding as in case 1, the tapered portion is ground to within the required distance of the top. Due to the slight

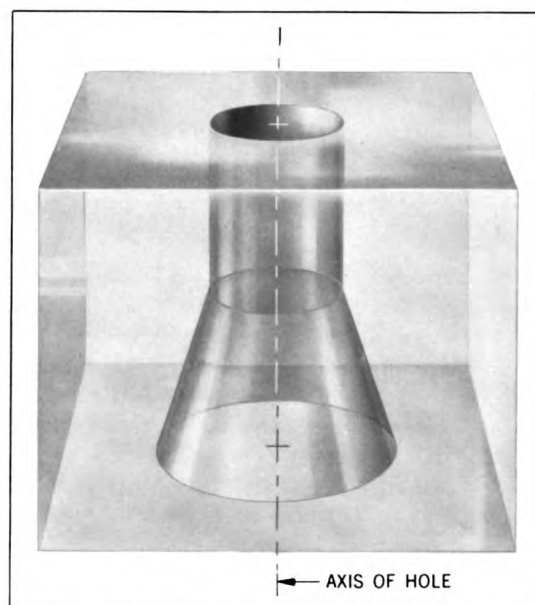


Fig. 152 — Frequently a portion of the hole must be cylindrical, the remainder tapered.

difference in angle and the high finish, the gradual advance of the taper toward the top is not always easy to observe. A line from top to bottom of the cylindrical hole, made with a pipe cleaner dipped in layout blue before starting taper grinding, will clearly show progress of the taper. This can be easily observed as the blue is cleaned away by the wheel, permitting the depth to be measured with a scale.

3. As an alternative method, where the hole is small or difficult to observe, it is sometimes more convenient first to grind taper to the top, as in case 1. The machine is re-set and the upper portion of the hole is ground straight.

The problem in this case is to determine the correct diameter of the end of the tapered hole in relation to the diameter of the cylindrical section, so that the latter will be of the correct length. Fig. 153 illustrates the conditions of this problem and provides a formula by which the correct diameter of the tapered hole may be calculated in relation to the length and diameter of the cylindrical portion.

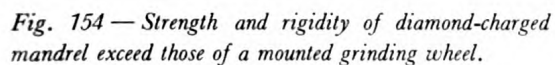
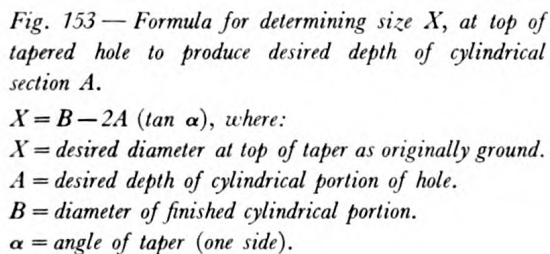
#### JIG GRINDING SMALL HOLES

The minimum diameter of holes that can be ground with an abrasive wheel is not easily established. Experience has amply proved, however, that diameters below  $\frac{3}{16}$ " cannot be ground *efficiently* with a conventional wheel. This limitation is imposed by the inherent weakness of such wheels and their shanks at efficient operating speeds, approximately 6,000 sfm.

An effective solution to this problem, permitting efficient grinding of holes down to  $\frac{1}{64}$ " in diameter, lies in the use of a diamond-charged mandrel as a grinding tool.

The advantages of this tool include:

1. Maximum rigidity and strength as compared to a grinding wheel, Fig. 154.
2. Mandrels can be "tailor made" to suit the exact requirements of each specific job, thus providing ideal relationship of tool diameter and length to that of the hole.
3. The sfm requirement for efficient grinding is approximately one-quarter that of a wheel.
4. Diamond powder is an ideal abrasive for both hardened steel and carbides.
5. The actual "cost per hole" is less than that of a wheel, due to greater efficiency.



Charging the working portion is accomplished as follows:

- [illegible]

A black and white photograph of a man in a workshop, wearing a dark shirt and apron, focused on his work. He is using a small tool to work on a piece of metal held in a vise. A small cup is visible in the background.

*Fig. 156 — Hammering produces the best results in charging.*

## HOLES, CONTOURS AND SURFACES

2. Hold the mandrel so that the working surface only lies on the block in the dust. Tap sharply with a small, hardened hammer while rolling the mandrel to charge the entire working surface uniformly, Fig. 156. Examination of this surface with a glass is a good guide while gaining experience in charging.
3. Dip the mandrel in acetone to remove all traces of oil.

The mandrel is mounted in the grinding head and spun by hand to detect any runout, which can be corrected by tapping very lightly as required. Before grinding, the hole should be cleaned with a pipe cleaner dipped in acetone.

Until experience is gained, the first instant of contact between mandrel and work is difficult to determine, because diamond dust does not produce a spark. The electronic amplifier, Fig. 157, makes this contact audible. It will be noted that the insulated parallels, available as an accessory, isolate the work electrically from the machine table.

Although holes longer than six times their diameter can be ground, the rapidly increasing spring of mandrels in proportion to their increased length makes this 6:1 ratio the practical limit.

During grinding the best results are obtained, both as to rate of stock removal and life of the mandrel, if a constant and uniform pressure is maintained between the mandrel and the work. This can be attained by keeping a "lead" of four or five "tenths" feed over cut until the hole nears size. Experience will enable an operator to hold this ratio by observing the rate at which the mandrel cuts and by outfeeding a "tenth" or two for each reciprocating stroke.

The following "tricks of the trade" should prove helpful in small-hole grinding:

1. Uniformly graded diamond powder should be used for charging mandrels. Holes from minimum to about  $\frac{3}{16}$ " in diameter should be roughed and finished with 80-100 grit powder. Larger holes may be roughed somewhat more rapidly with a coarser grade, 60-80 grit.
2. Avoid bellmouth by preventing the mandrel from leaving the hole at either end.

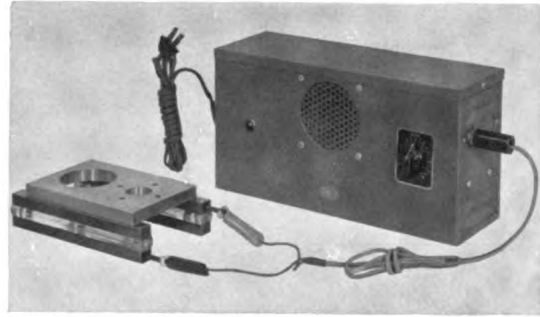


Fig. 157 — Amplifier makes contact between mandrel and work audible.

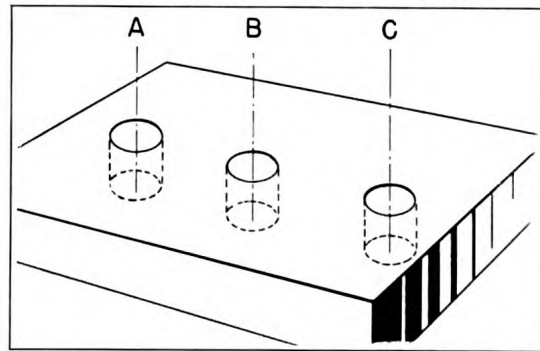


Fig. 158 — In grinding three holes to size, A and B are roughed to within .001" — .002", and C within about .005". Using a freshly charged mandrel, C is finished to size, thereby breaking down the high points on the tool. A and B may now be safely ground to size.

3. Since a freshly charged mandrel will cut much more rapidly than a worn one, avoid introducing a freshly charged tool as a hole nears size, Fig. 158.
4. Do not permit the uncharged *shank* of a mandrel to contact the surface being ground. Frictional heat will burn both the work and the mandrel. The former, partially annealed at point of such contact, will charge with the diamond dust and probably be ruined.
5. It is generally more economical and efficient to consider mandrels as expendable and make a new one for each job. Since the cost is only about 30 cents, use of an old one, or even the time spent trying to match one to the requirements, is hardly justified.
6. Because mandrels cannot be trued with a diamond, it is necessary to measure both the top and bottom of a hole while grinding, in order to avoid a ridge.

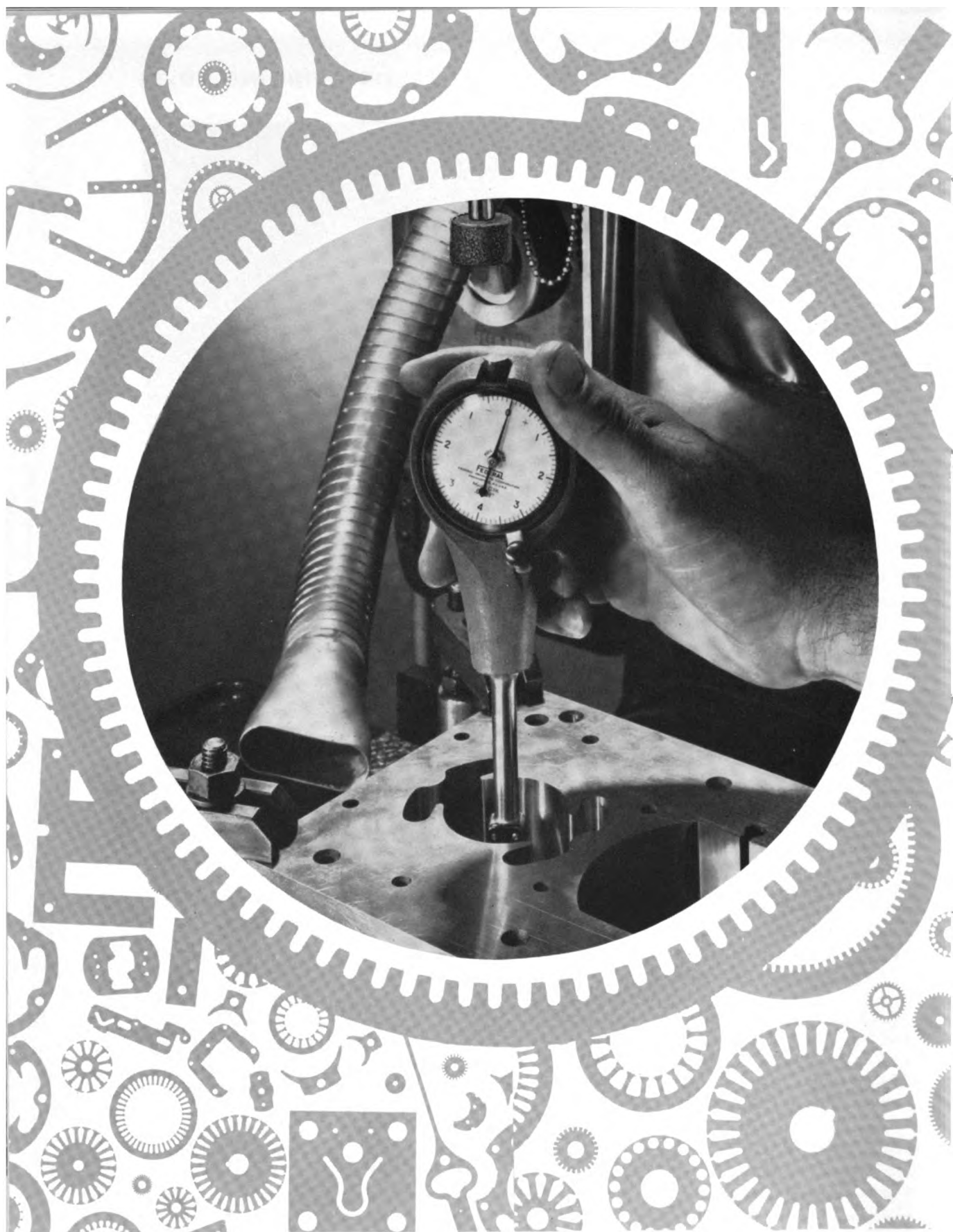
7. In view of point 6, it is advisable to set the work up on parallels of sufficient height to enable measurement from beneath the workpiece, Fig. 159.

## GENERAL HOLE-GRINDING PRACTICES

1. Lock the machine travels securely before grinding.
2. Rough holes before finishing any of them. This is an excellent precaution against setting errors. Where the highest accuracy is required, allow time for the workpiece to cool to room temperature before proceeding with finish-grinding.
3. Avoid grinding excessively long holes, if possible. Often cooperation of the designer permits a portion of the length to be relieved.
4. A wood wheel, turned from maple and rolled in fine lapping compound, will produce a "superfinish" without materially altering size.
5. Avoid attempting to finish a hole with a glazed wheel, even though within a tempting "tenth" of size.
6. Demagnetize the work before setting up.
7. Keep the wheel freshly dressed when grinding thin sections. A glazed wheel will cause local heating, distortion and locational error.



*Fig. 159 — Workpiece is mounted high enough to permit measuring bottom as well as top of hole.*



*Jig Grinding Contours.*

## JIG GRINDING CONTOURS

THE SAME combination of planetary and reciprocating motions, together with precise rectilinear positioning, which enables the Jig Grinder to locate and size straight or tapered holes accurately, makes it suitable for contour grinding. Other features specifically designed to facilitate this operation also make it a "natural" for contours.

Reference to construction details, Chapter 8, shows that the vertical, reciprocating members are located within, and rotate together with, the main spindle. Direct control of main spindle rotation within any desired arc is possible, as a result, by means of the handwheel, worm and gear assembly, Fig. 134. The significance of this control in contour grinding will be explained later.

Briefly reviewing the principle of full planetary movement of the Jig Grinder as employed in grinding a hole, Fig. 160 shows the relationship of the grinding spindle rotation to the axis of the main spindle. The diameter of the hole is controlled by increasing this radius of movement of the grinding spindle about the axis of the main spindle, or *outfeeding* the wheel. Fig. 161 shows the principle applied to a portion of a hole.

In Fig. 162, a stud or male cylindrical member has been shown in place of a hole. It is apparent from this substitution that its O.D. can readily be ground by reducing the radius of movement of the grinding spindle from the axis of the main spindle, or *infeeding* the wheel, to control the diameter of a male

member. In effect, this is an inside-out hole grinding operation.

Combining these conditions in grinding the contour shown in Fig. 163 introduces one additional requirement, restriction of main spindle rotation to an arc, within which it must oscillate while grinding the limited male radii. The connecting female radii are ground as portions of a hole, using full rotation of the main spindle. Thus, the combination of full and limited planetary motion in grinding, with rectilinear positioning for accurately locating each center from which a radius is generated, enables the grinding of any contour composed of radii, male and/or female, Fig. 164.

The method of controlling the limits of arc of the main spindle is described under "Angular Arc Setting," page 120. The actual setting

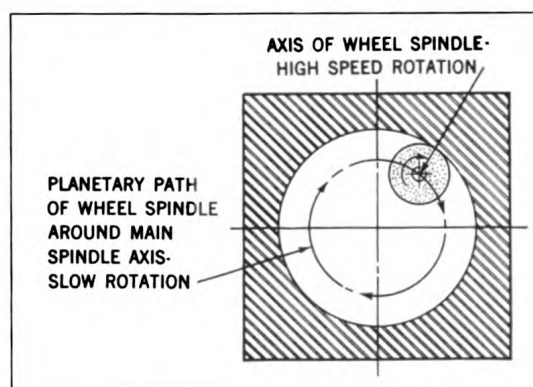


Fig. 160 — Relative movement in simple planetary grinding.

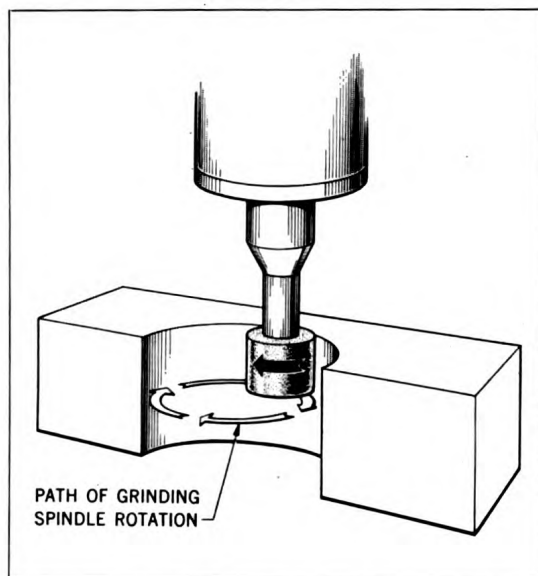


Fig. 161 — A portion of a hole is ground in the same manner. Rotation of main spindle may be limited to an arc, should an obstruction necessitate it.

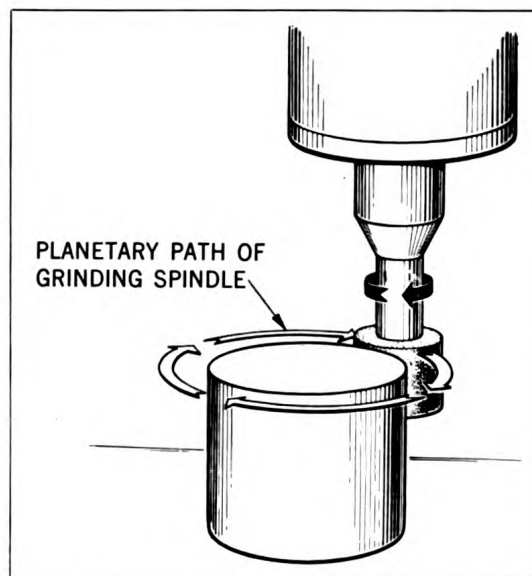


Fig. 162 — Planetary grinding of a stud merely involves feed reversal. A male radius merely requires limiting main spindle rotation to an arc.

of the stops may be made from angular values given on the workpiece drawing or, in a case similar to the one just described, from the coordinate locations of the limiting radii.

**Contour Measurement** — The sole remaining problem at this point is measurement of the rather awkward portions of such contours as do not lend themselves to the use of conventional plugs or gages. Yet the efficiency of contour grinding is largely predicated upon the ability to check size conveniently during grinding and in final inspection. Fortunately, the *lead screw* measuring system of the Moore Jig Grinder is ideally suited to perform this otherwise difficult task. With an indicator held in the clamp ring, Fig. 165, the accuracy of the lead screw can be directly used in measuring *any* dimension of a contour, in the following manner:

1. Any ground edge, square to one travel of the machine, can be centered under the axis of the main spindle by use of the edge-finder (see page 98). If the workpiece does not provide a convenient edge for this purpose, a parallel setup block may be mounted somewhere on the table, Fig. 166.
2. For measuring a female radius such as the

1.2360" dimension in Fig. 167, the edge is moved *away* from the spindle axis by a distance equal to the specified radius as measured by the lead screw, Fig. 168, in this case 1.2360". The indicator is positioned to register against the edge and its dial set to zero, Fig. 169. Be sure to swing the main spindle to pick up the high point while making this setting. The indicator now registers zero against a point exactly 1.2360" from the spindle axis.

3. Re-position to bring the point of origin of the radius again in line with the spindle axis and bring the indicator point into contact with the

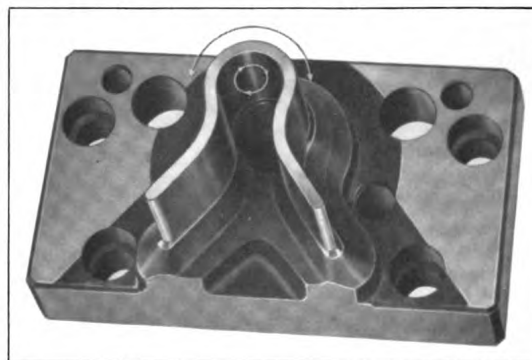


Fig. 163 — Grinding a contour such as this punch is a combination of the methods shown in the three preceding illustrations.

## JIG GRINDING CONTOURS



*Fig. 164 — This contour can be Jig Ground to dimensions within .0001" in approximately 25 hours.*

surface to be measured, Fig. 170. The difference between the indicator reading and zero shows the relationship of the radius as it exists, in comparison to the nominal value to be established, i.e., 1.2360", thus showing how much stock remains to be ground.

4. The location of a straight surface can be measured in the same manner.

5. Male radii are measured by the same technique except that in this case the edge is moved *past* the spindle axis, Fig. 171, by the desired distance.

In this way the makeshift and time-consuming use of special gages, templates, construction holes and external reference points is eliminated in favor of the accurate, efficient and direct use of the machine's own measuring system.

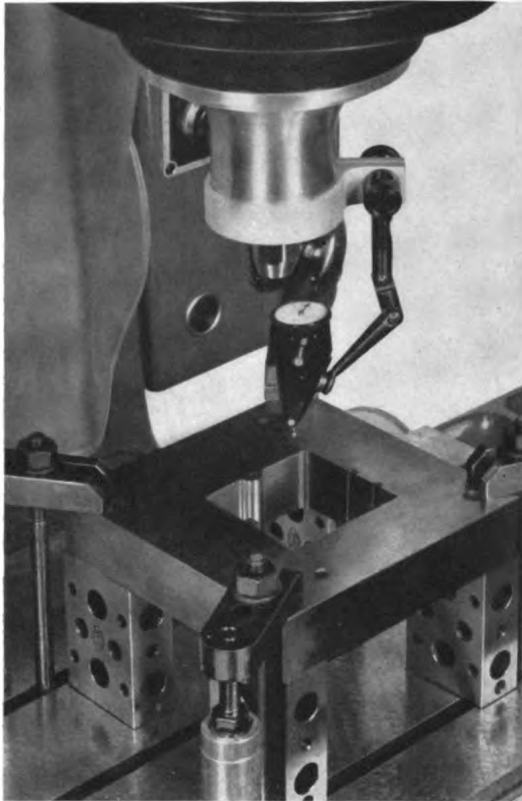


Fig. 165 — The indicator, though mounted on the grinding spindle, is controlled by the main spindle.



Fig. 166 — A parallel setup block provides a convenient reference edge for indicator measuring.

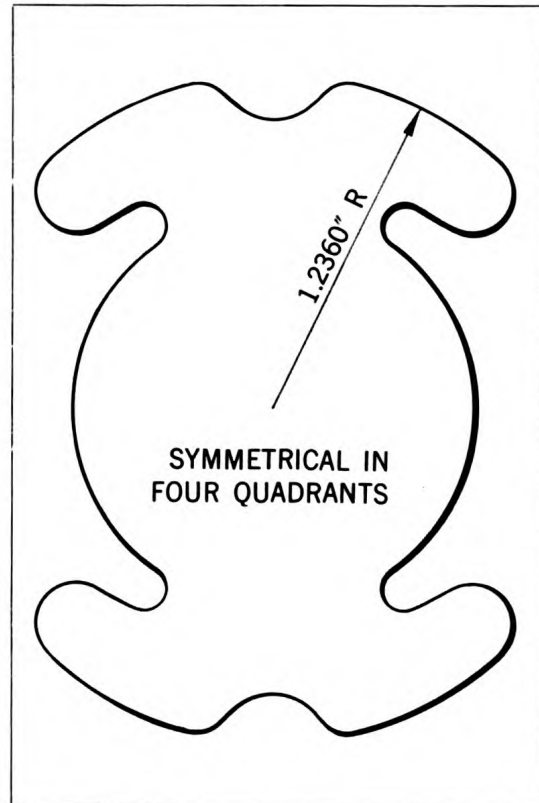


Fig. 167 — The 1.2360" dimension represents a typical example of contour measuring. In the interest of clarity, the coordinates shown in Fig. 63 have been omitted.

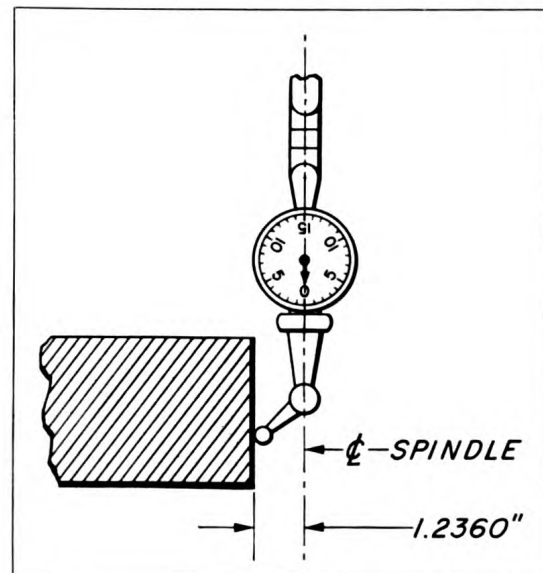


Fig. 168 — Indicator set against reference edge for measuring female radius.

## JIG GRINDING CONTOURS

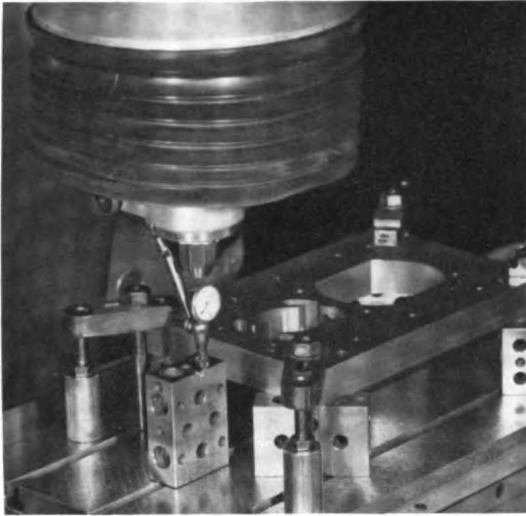


Fig. 169 — Relation of reference edge, scales and dials.

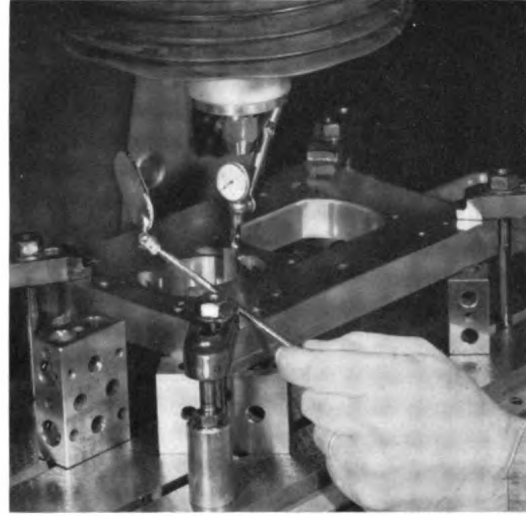


Fig. 170 — Measuring the workpiece radius.

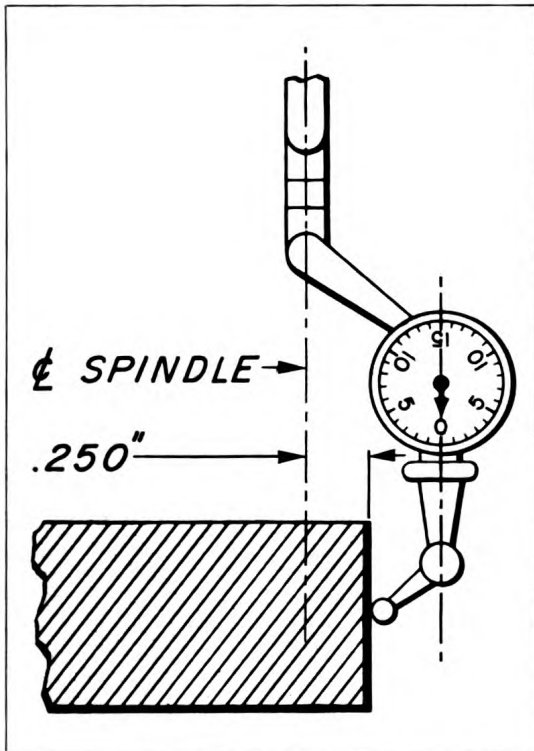


Fig. 171 — The reference edge must be moved past the spindle axis in order to measure male radii.

The rotor station of the stator-rotor lamination die, Fig. 172, represents a practical application of contour grinding and indicator measuring. The entire contour can be ground

to size within a "tenth," including proper draft, in 25 hours — a fraction of the time required by any other method. Fig. 173 illustrates the steps involved in this job, each portion ground directly to figures from the thirteen coordinate positions representing points of generation of the respective radii. The thirteen positions are established directly, by successively positioning the table according to the measuring system.

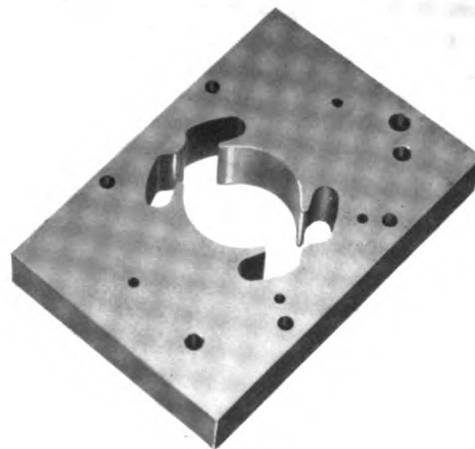


Fig. 172 — This contour of the stator-rotor lamination die is an ideal example for illustration of contour Jig Grinding methods.

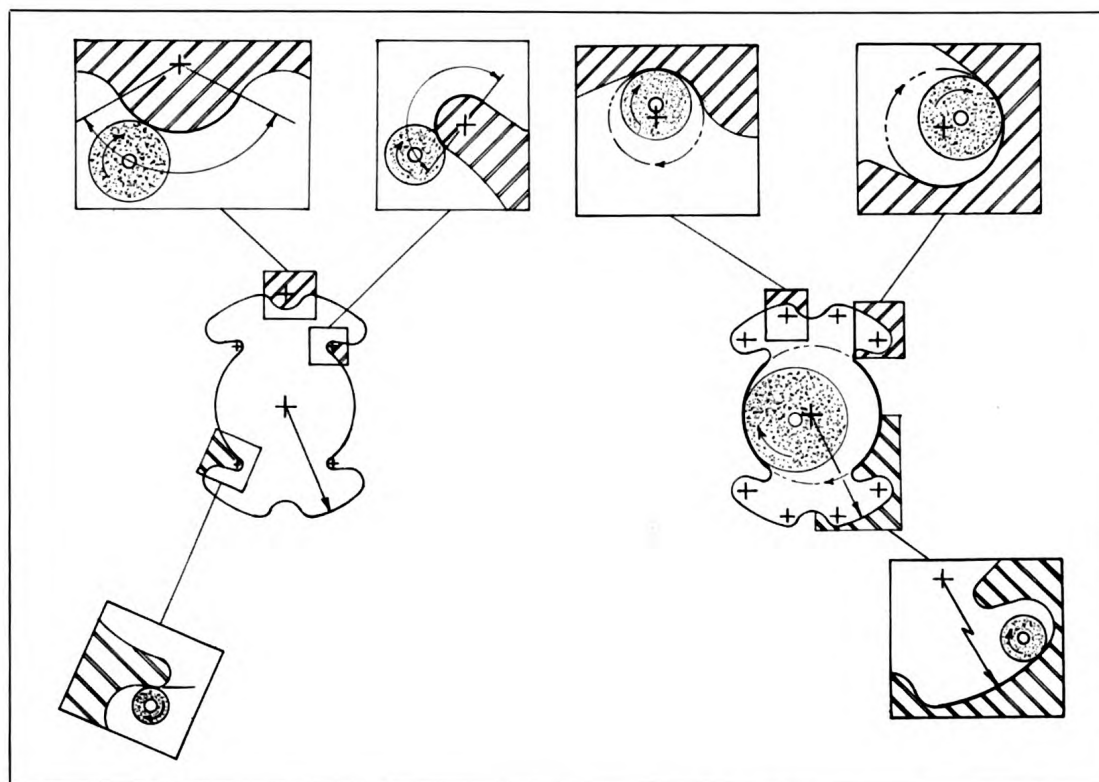


Fig. 173 — Step-by-step operations in grinding the contour of the die shown in Fig. 167.

It may readily be recognized that the matching surfaces of the mating punch, Fig. 174, can be contour ground to the same coordinate layout by the same technique. Indicator measuring permits accurate sizing for required clearance.

Directness, accuracy and ease of operator visualization of the preceding method may be contrasted with the method necessary in the case of Jig Borers converted to grinding, or Jig Grinders of related construction. In the latter, a spindle rotates *within* the reciprocating member or quill. In this construction there are no convenient means of controlling the limited arc of spindle movement necessary in contour grinding.

In this case, the oscillating movement must be transferred to the workpiece by mounting it on a rotary table. To position the workpiece and bring the point of origin of various radii successively over the center of table rotation, a compound or rectilinear slide is mounted

on the rotary table and the workpiece, in turn, mounted on its uppermost slide.

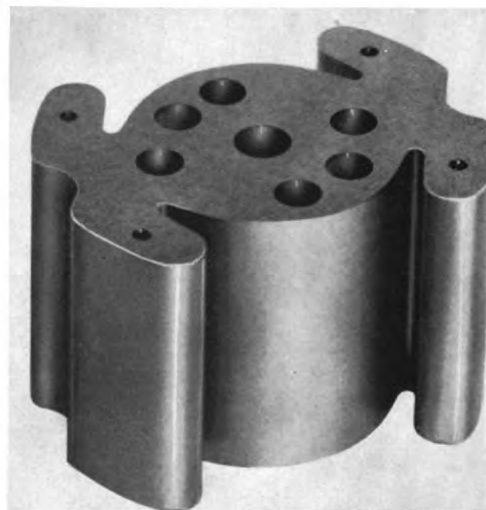


Fig. 174 — Insurance of uniform clearance results from the ability of the Jig Grinder to contour-grind punch as well as die of the stator-rotor lamination press tool.

## JIG GRINDING CONTOURS

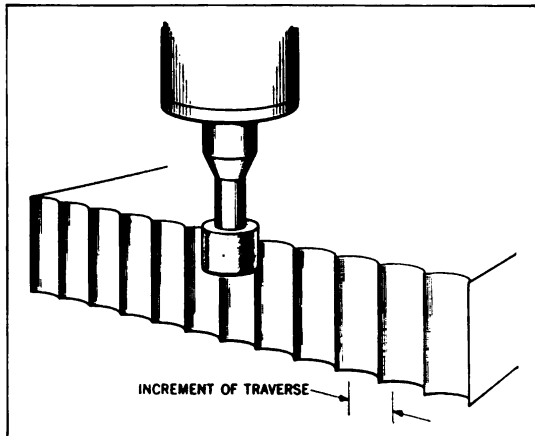


Fig. 175 — Increments of feed control chop-ground surface finish.

Feeding the wheel to control size must thus be related dimensionally and geometrically, not to the main spindle axis, but to the rotary table axis. This necessitates accurate alignment of the slide controlling this movement with the travel of the compound, and rigidly locking it against angular shift. Significant shortcomings of this method of contour grinding include:

1. The measuring system of the machine, with its accuracy, rigidity and range of rectilinear movement, does *not* control the locations of the contour. Instead, this responsibility is delegated to an auxiliary member, the rotary table-compound combination. This accessory cannot conceivably be equivalent in accuracy to the corresponding functions of the machine itself.
2. Because of the number of requisite steps, all of which represent potential sources of dimensional errors, the cumulative sum can be appreciable:
  - a) Picking up the center of table rotation in relation to spindle axis;
  - b) Orienting the workpiece to the measuring system of the auxiliary compound, both geometrically and dimensionally;
  - c) Picking up the workpiece in relation to the axis of both the spindle and rotary table;
  - d) Aligning the wheel outfeed slide with the machine travel and locking against angular shift. Portions of contours to be ground with full planetary rotation require repetition of this step before reverting to arc grinding.
3. In addition to the dimensional errors from the

above sources, the indirectness, complexity and multiplicity of moves present a serious problem of operator visualization.

In effect, this technique falls short of the fundamental aspects of true coordinate contour generation. Only a Jig Grinder capable of completing all contours while the workpiece is continuously integrated with the machine's measuring system fulfills these requirements.

**Contour Stock Removal** — In addition to the plunge and outfeed grinding technique described in relation to hole grinding, contour grinding benefits from the following methods of stock removal:

1. *Chop grinding*, which may well be described as a vertical shaper movement, with the wheel as a tool. It enables rapid stock removal, finish being controlled by rate of traverse, Fig. 175.
2. *Wipe grinding*, used for finer finish, is similar to surface grinding; there is no vertical movement, Fig. 176.

**Horizontal-Spindle Contour Grinding** — Enclosed contours presenting problems of straight surfaces and angles can best be ground with the horizontal-spindle "slot grinder" attachment, Fig. 177. This accessory can be substituted for the vertical-spindle grinding head to grind sharp corners, an indispensable addition to the capabilities of the machine.

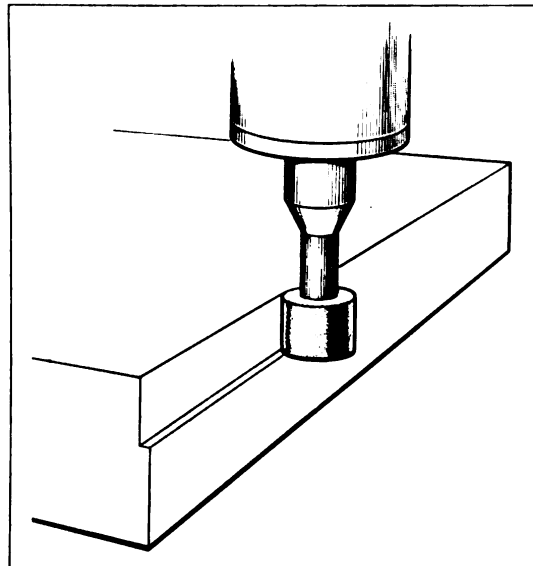


Fig. 176 — Face contour of wheel controls surface characteristics in wipe grinding.



Fig. 177 — "Slot grinder" attachment rounds out the contour grinding capabilities of the No. 2 Moore Jig Grinder.

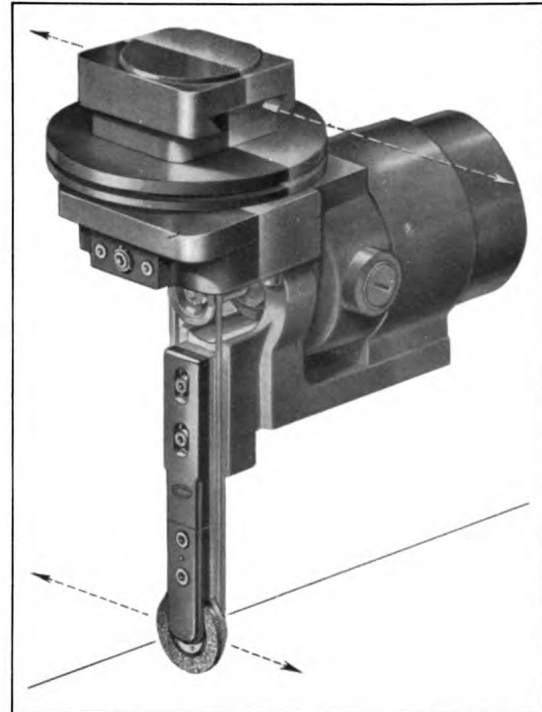


Fig. 178 — Normal relationship of "slot grinder" spindle to outfeed travel.

Although the horizontal spindle axis is nominally normal to the travel of the outfeed slide, Fig. 178, its rotatable mounting, Fig. 179, permits any other desired angular relationship. Such a requirement may arise because of obstructions in the contour which necessitate "cocking" the wheel, or because draft must be ground in the side of a slot, Fig. 180.

A slide, integral with the mounting element of this attachment, provides for axial adjustment of the wheel position, so that it can be set radial to, or offset from, the main spindle axis, Fig. 179. This adjustment is necessary in centralizing angles dressed on the wheel face, and for dressing a wheel to grind a slot central in the bore of a hole, Fig. 181.

The stator blanking station, Fig. 182, of the stator-rotor lamination die represents a typical application of the horizontal spindle, the requirement of sharp corners precluding the use of the vertical-spindle grinding head. Reference to Fig. 183 illustrates the applica-

tion of the slot grinder to grinding this opening. The radii are ground by slowly swinging

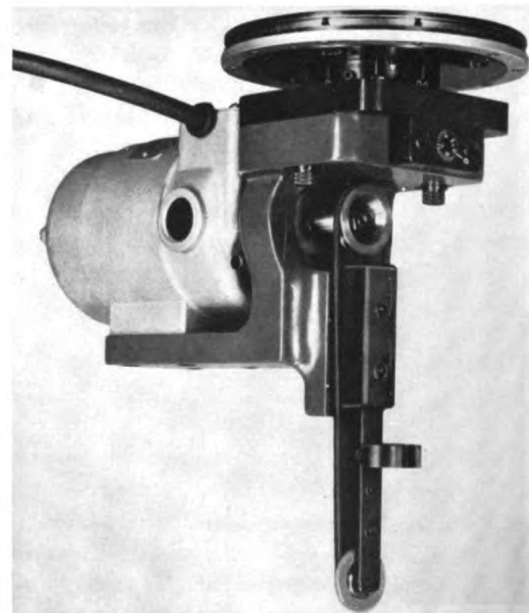


Fig. 179 — Rotatable mounting ring of "slot grinder" permits angular orientation of wheel axis to outfeed travel.

## JIG GRINDING CONTOURS

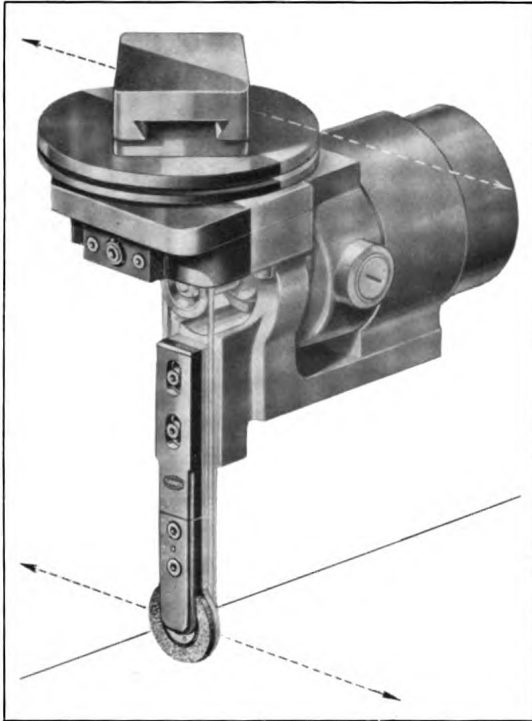
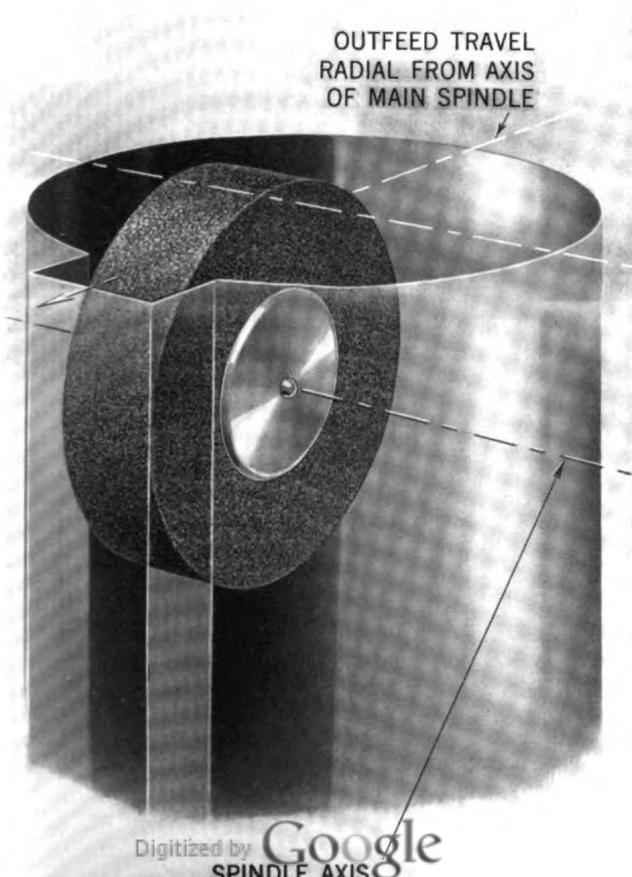


Fig. 180 — Space limitations often require angular relation of wheel to outfeed travel.

Fig. 181 — Centrality of wheel to main spindle axis is necessary in grinding this typical job.



the main spindle through the arc limited by the adjoining straight surfaces, while the wheel is reciprocated vertically. The straight surfaces are ground by traversing them past the wheel by movement of the table.

Straight surfaces not parallel to table travel can be similarly ground by mounting the work on a rotary table. In this way the surface to be ground can be aligned with the travel for that operation and returned to setup position again without upsetting the relationship of workpiece to measuring system.

**Horizontal-Spindle Wheel Dressing** — Dressing radii for roughing, and occasionally for finish grinding, can be accomplished with sufficient accuracy with the hand-held tool, Fig. 184. Using Fig. 182 as an example, the diamond point is positioned just *inside* the edge of the radius, using a pocket scale or equivalent as a straightedge, Fig. 185. The wheel is swung back and forth past the diamond by movement of the main spindle through an arc, gradually outfeeding until the wheel is dressed clean.

Thus dressed, the radius on the wheel will be somewhat smaller than that to be ground on the work. The resulting finish will depend on how small an increment of radial feed is

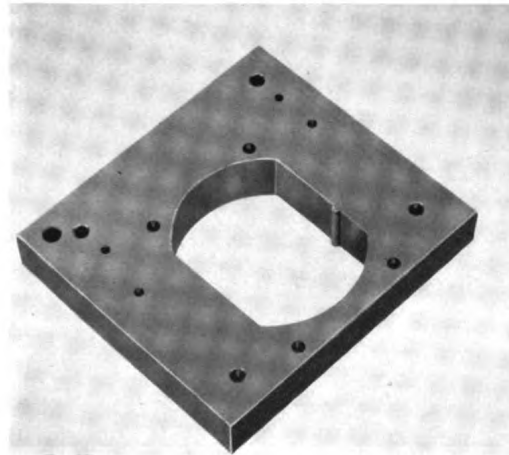


Fig. 182 — Both the radii and straight surfaces of the stator blanking station of the stator-rotor lamination die are most efficiently ground with the horizontal spindle attachment on the Jig Grinder.



*Fig. 183 — Contour grinding the blanking station.*

used, since, in effect, a series of scallops of slightly non-conforming radius will be produced. A radius may be dressed on the wheel which will exactly conform with that to be ground by mounting a diamond on the machine table in a known position in relation to the measuring system. Fig. 186 shows a convenient method of mounting. The back

edge of the fixture can be picked up with the edge-finder, Fig. 187, and the dimension from this surface to the tip of the diamond measured with a micrometer, Fig. 188. Thus the location of the tip can be established in relation to the spindle axis and coordinate system.

Referring again to Fig. 185, the 1.8430" radius can be dressed on the wheel by posi-

## JIG GRINDING CONTOURS



Fig. 184 — The necessary face radius is dressed on the wheel, using a diamond tool clamped or held in the correct location.

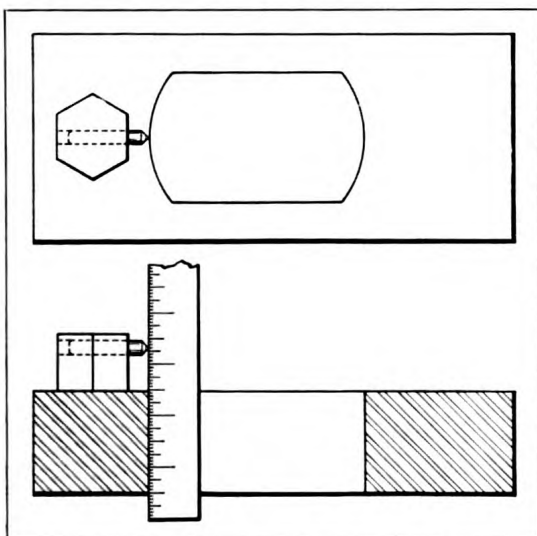


Fig. 185 — Use of straightedge to determine diamond position preparatory to dressing radius on face of wheel.



Fig. 186 — A diamond mounted in this convenient accessory can be accurately positioned to dress a radius of predetermined size.

tioning the main spindle axis 1.8430" from the known position of the diamond and dressing as in the preceding case, Fig. 189. It is important in dressing *any* form on the wheel to position it vertically, so that its axis is in line with the diamond. A convenient means of establishing this is to swing the main spindle so that the small hole in the side arm can be visually aligned with the tip, Fig. 190. Failure



Fig. 187 — First step in positioning diamond is pickup of edge of holder.



Fig. 188 — Relationship of diamond point to edge of holder is established by micrometer measurement.

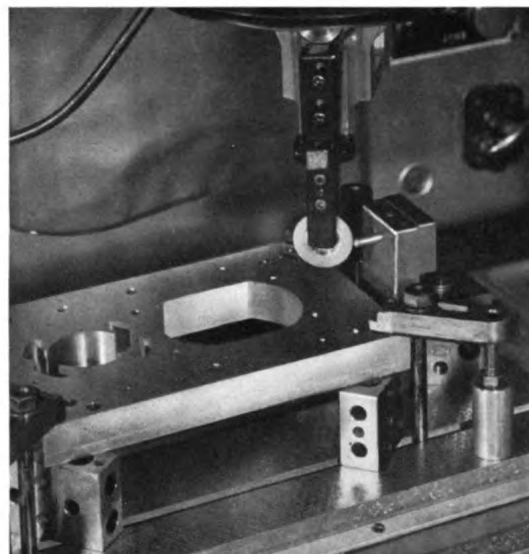


Fig. 189 — With the main spindle axis at the proper distance from the now established position of the diamond point, the wheel is fed to the latter to produce the desired radius.

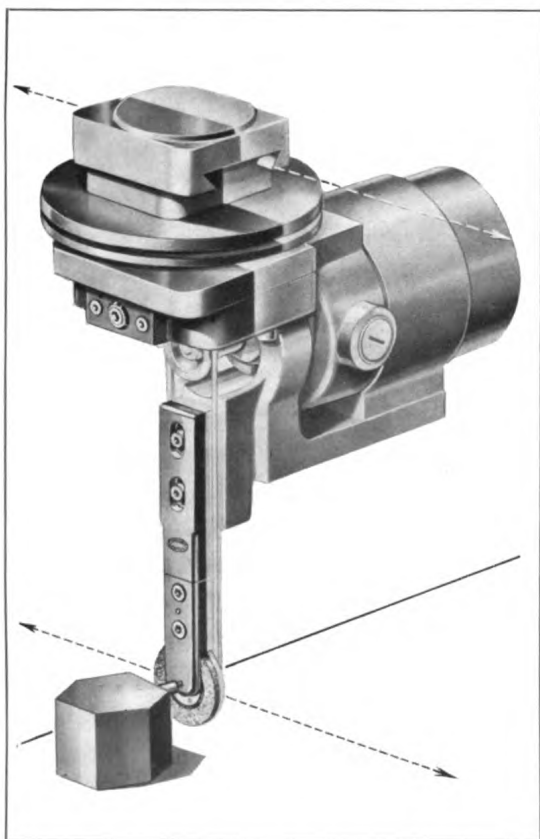


Fig. 190 — Visual vertical alignment of wheel spindle axis with diamond point is sufficiently accurate to prevent foreshortening of form.

to establish this relationship will foreshorten any form so dressed.

Fig. 191, showing an enlarged section of the lamination die, Fig. 192, reveals another application of the same dressing technique, with the additional requirement of parallel sides tangent to the radius as a means of establishing slot width. In this case, the wheel should be centralized, Fig. 193, by means of the adjustment shown in Fig. 179.

After dressing the radius to  $90^\circ$  either side of center, as read on the graduated ring, Fig. 194, the table carrying the diamond is traversed, as shown in Fig. 195, to dress the sides of the wheel tangent to this radius. This se-

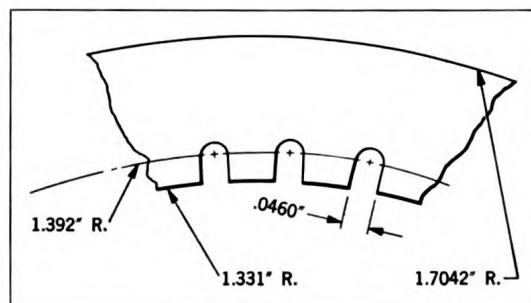


Fig. 191 — Enlarged view of serrated die section.

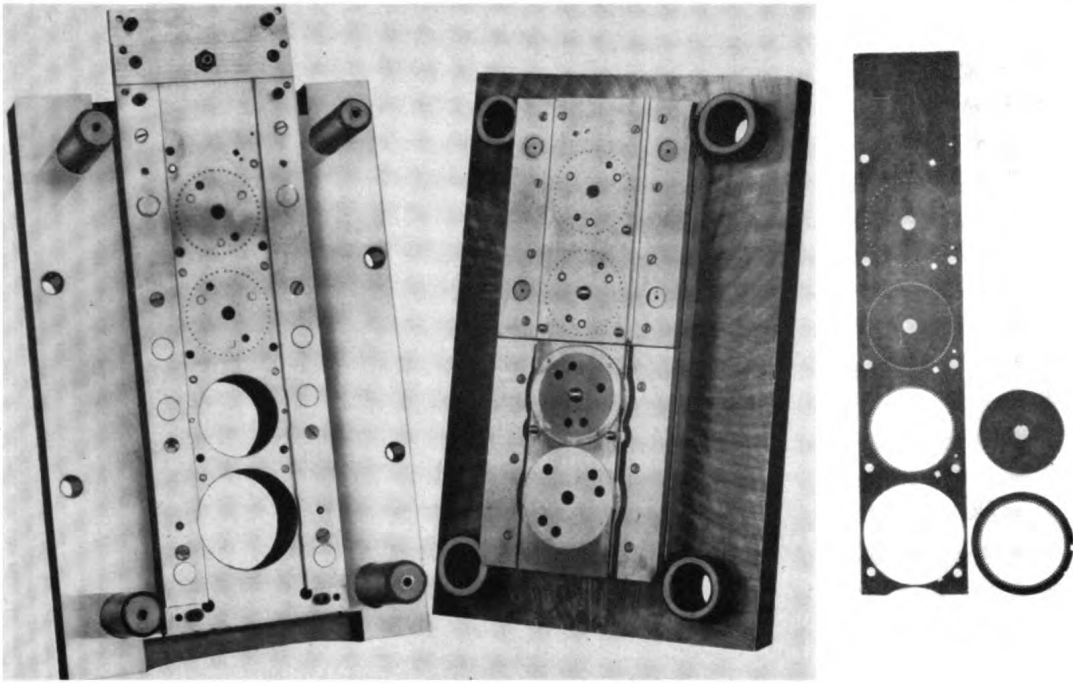


Fig. 192 — Complete serrated die for lamination stamping.

quence is repeated until the wheel is dressed clean and to the requisite width.

Angles may also be dressed by a diamond mounted in a known location. The desired

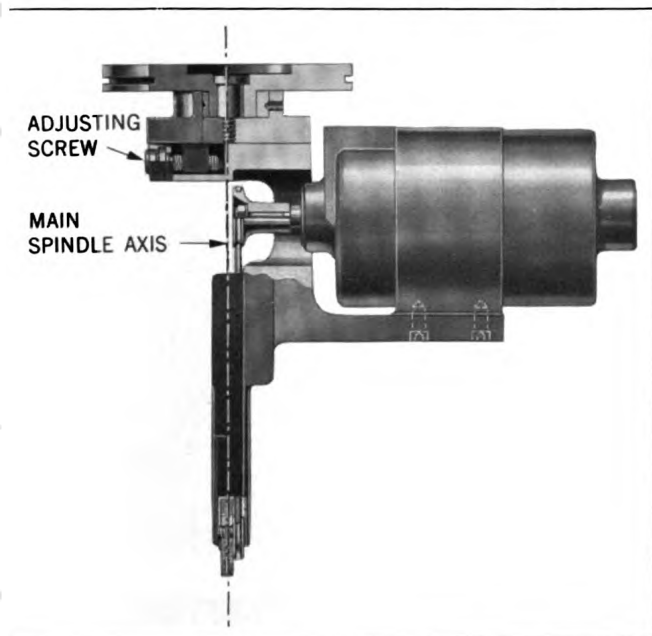


Fig. 193 — Centralizing wheel by adjustment of "slot grinder."

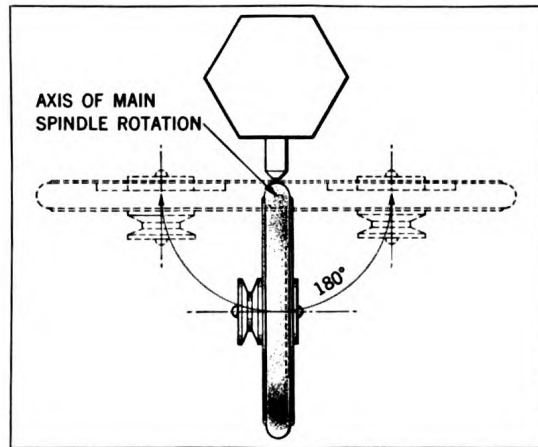


Fig. 194 — Dressing radius on wheel face.

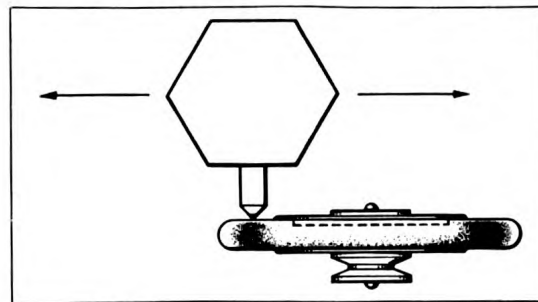
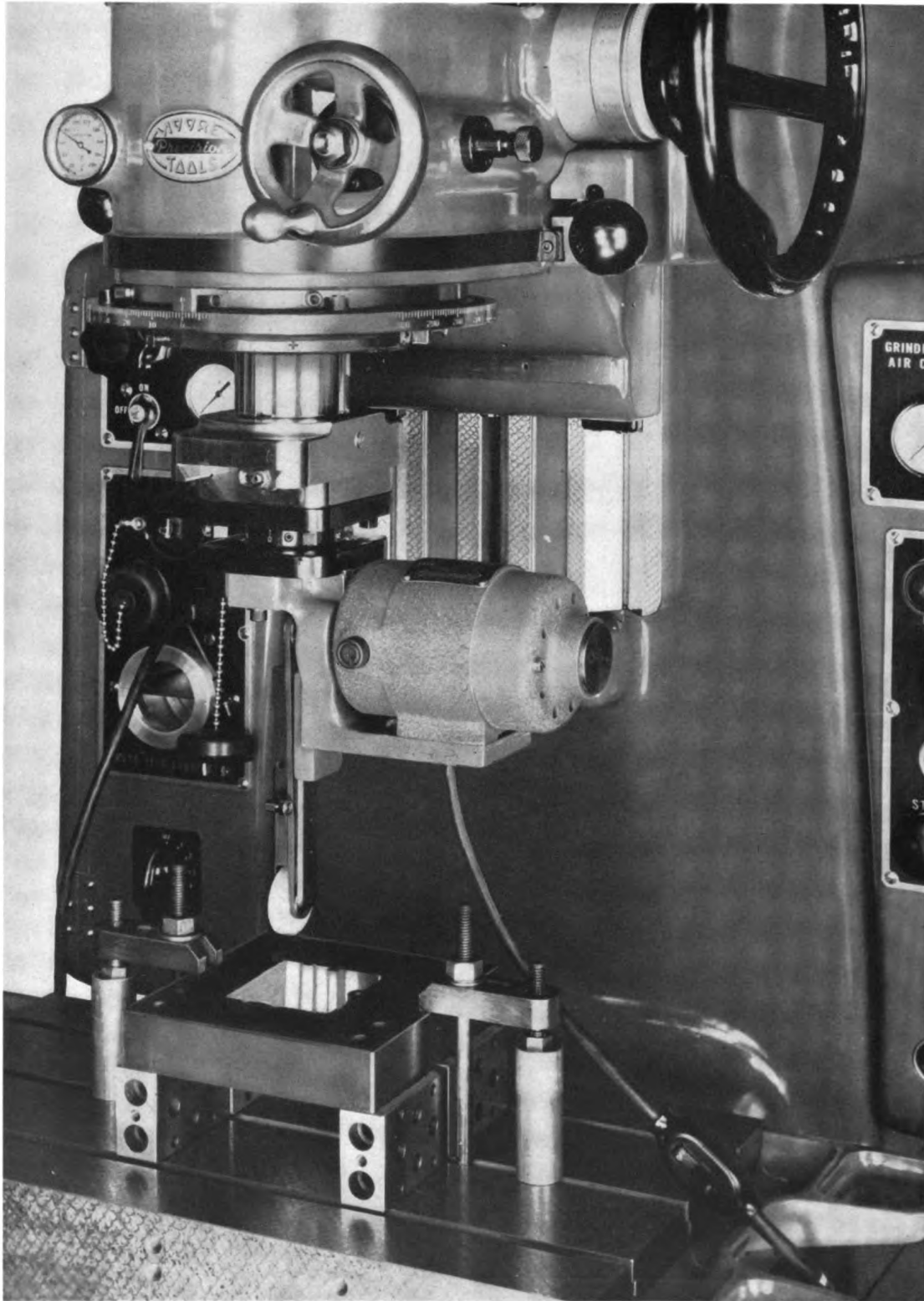


Fig. 195 — Dressing sides of wheel tangent to radius.



*Fig. 196 — Angle dressing of wheel is facilitated by graduated ring.*

## JIG GRINDING CONTOURS

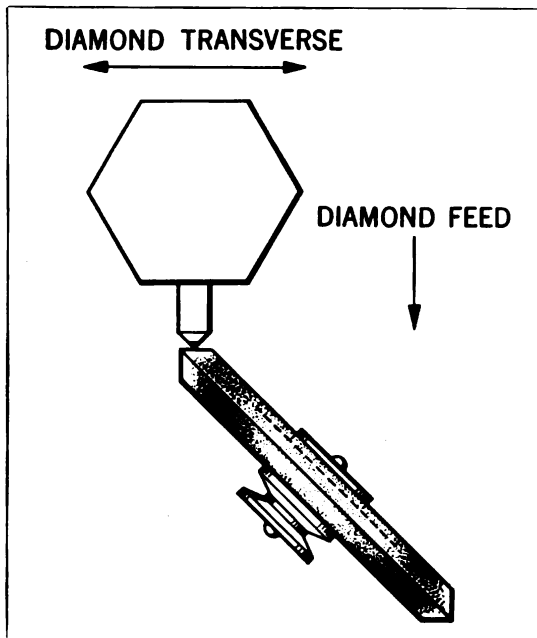


Fig. 197 — Relation of feed and traverse in angle dressing.

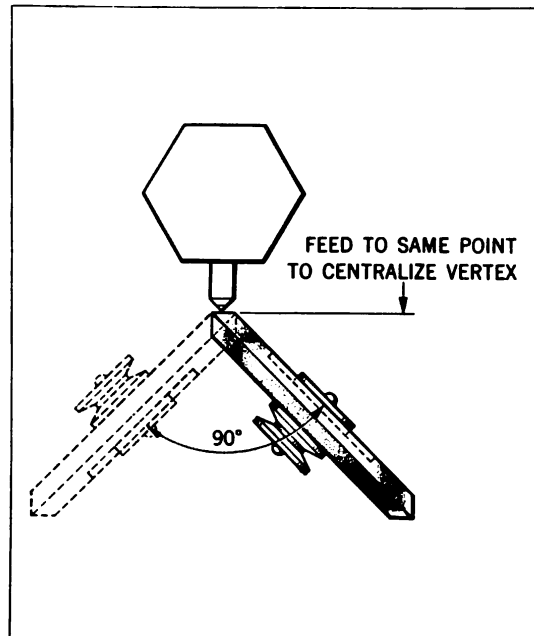


Fig. 199 — Feeding to same setting on both flanks of angle centralizes vertex.

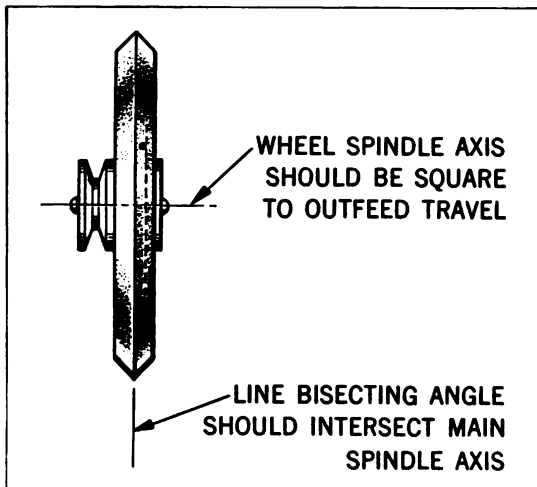


Fig. 198 — Relation of angle vertex to spindle axis.

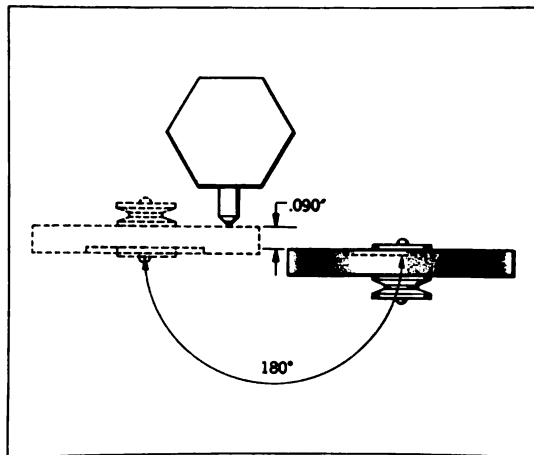


Fig. 200 — First step in centralizing wheel requires measurement of offset.

angle is set by graduations on the ring, Fig. 196, and dressing accomplished by traversing the table and diamond past the wheel flank while feeding with the other lead screw, Fig. 197. The second flank is similarly dressed. The vertex of the angle thus produced can be centralized in relation to outfeed travel and the main spindle, Fig. 198, by feeding to the same lead screw dial graduation on both

flanks of the angle, Fig. 199, during dressing.

For slot grinding, it is frequently necessary to dress a wheel to a required width and central. This is accomplished by the following steps:

1. Assume that the undressed wheel is off-center, and when rotated through 180° shows an offset of .090", Fig. 200, measured by moving the table until the diamond does touch.
2. Move the diamond and table to the mean posi-

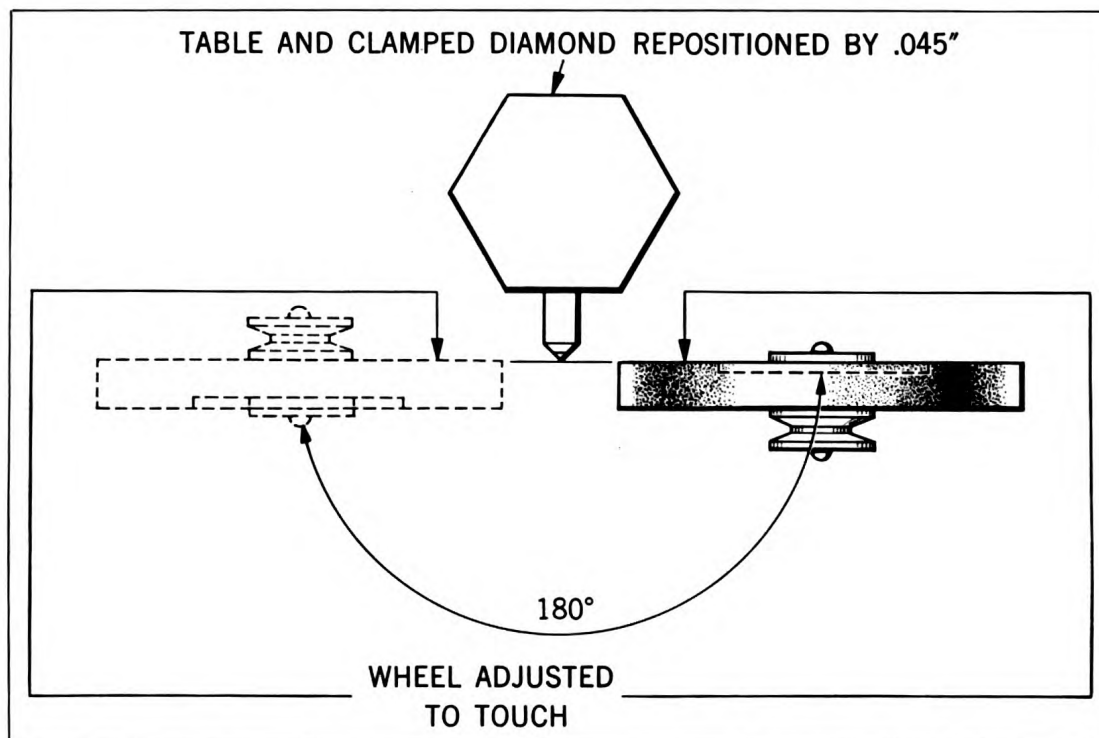


Fig. 201 — Wheel is approximately centralized by correction of  $\frac{1}{2}$  of measured offset.

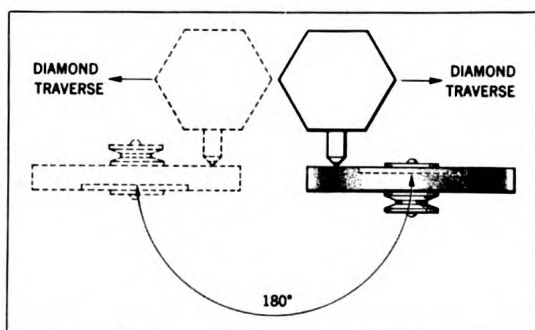


Fig. 202 — The correctness of this move is proved by brushing contact with diamond in two positions  $180^\circ$  apart.

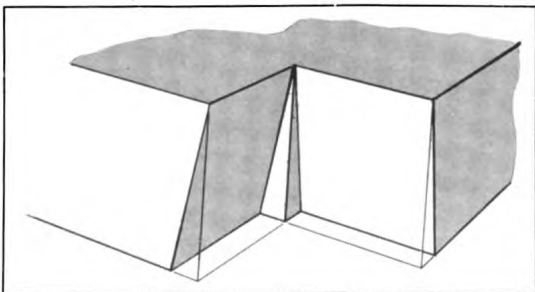


Fig. 203 — Draft, measured in a plane bisecting a corner angle, is not the same as measured normal to the side surface.

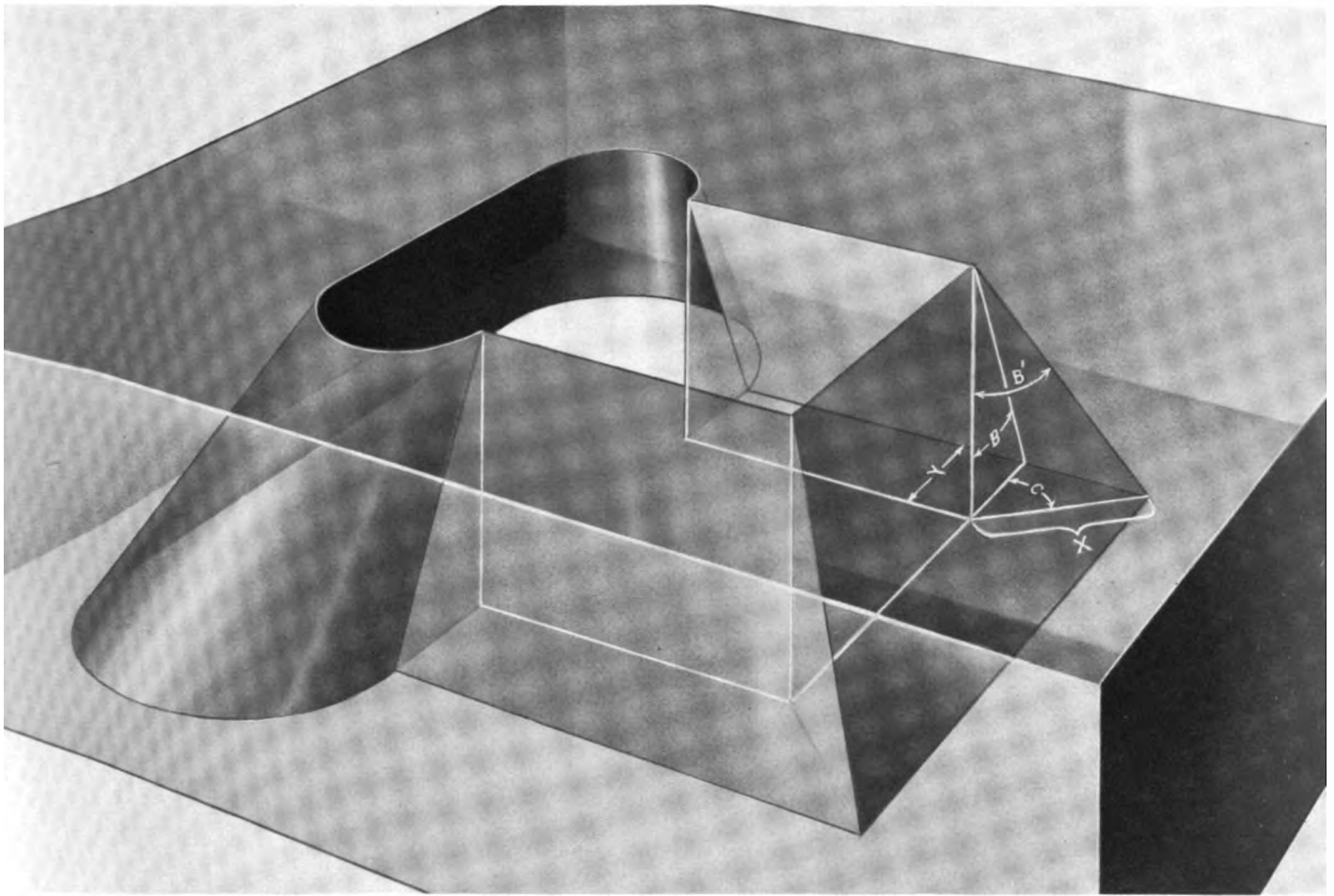
tion, Fig. 201, and position the wheel by means of the adjustment, Fig. 177, so that brushing contact is made between the wheel and diamond, Fig. 202. Rotated  $180^\circ$ , the wheel should now exhibit the same brushing contact with the diamond on the opposite flank.

3. Dress the sides by traversing the table and diamond while feeding, as shown in Fig. 195, until the wheel is clean or, if necessary, until the desired width is attained.

This attachment permits grinding a wide variety of forms, including splines, gear teeth, keyways and virtually any portion of a contour which cannot be ground with the vertical-spindle grinding head.

**Draft in Contours** — Draft in contours composed of radii is ground in the same way that would be accomplished in a hole. Intersections of straight surfaces, however, introduce a new problem. Fig. 203 shows a right angle corner with  $\frac{1}{2}^\circ$  draft on each of the intersecting straight surfaces. Grinding into the corner with the same taper setting would fail to produce a blend, but correction of the angle

## JIG GRINDING CONTOURS



C = 1/2 CORNER ANGLE

Y = TAPER OF SIDE, IN THOUSANDTHS

X = TAPER IN BISECTING PLANE, IN THOUSANDTHS

B = TAPER ANGLE IN PLANE NORMAL TO SIDE

B' = TAPER ANGLE IN PLANE BISECTING CORNER

ANGLE

X = Y COSEC. C

OR

B' = B COSEC. C (APPROX.)

EXAMPLE: CORNER ANGLE = 90°

C = 45° X = 1.4142Y

EXAMPLE: FROM ABOVE, WITH

B' = 1° B' = 1° X 1.4

B = 1.4° - 1° = 24'

Fig. 204 — Formula for deriving corner draft angle to blend with given side angle.

of taper, as determined by application of the formula in Fig. 204, will remedy this situation.

**Production Jig Grinding** — Although essentially a toolroom machine, the Jig Grinder in many instances provides an effective solution to the difficult problem of accurately sizing and locating holes, studs and contours in hardened production parts.

Use of an adjustably mounted diamond to automatically dress the wheel, as a means of size control, is a principle which can be successfully applied to a widely varied range of repetitive work. Typical of this use of the machine is the high-production operation on an aircraft gear, Fig. 205, involving a battery of sixteen Jig Grinders.

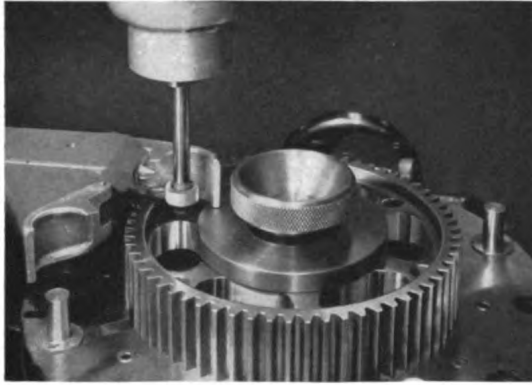


Fig. 205 — Jig Grinding aircraft engine gears with indexing fixture and automatic wheel sizing.

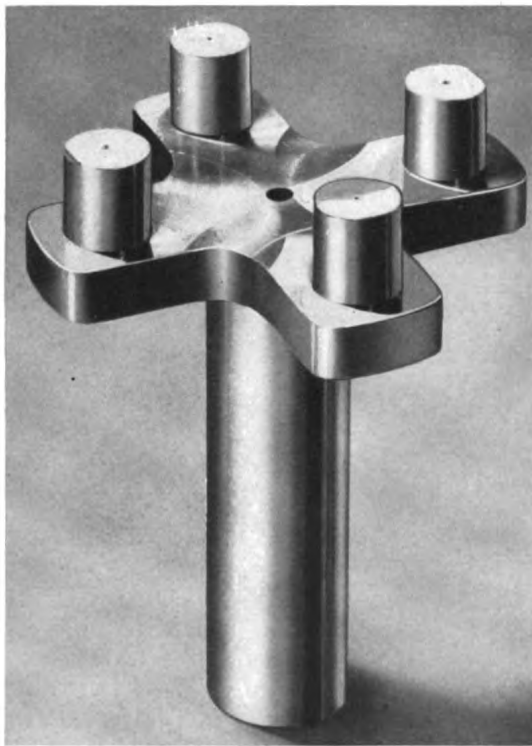
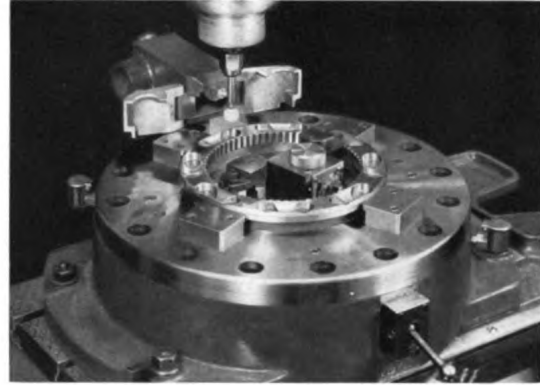


Fig. 206 — Unusual but practical production Jig Grinding job.

The location, diameter and surface finish requirements of the four studs on the part shown in Fig. 206 present a really serious problem of production technique. Set up for Jig Grinding, Fig. 207, each of the four studs was ground in a single plunge cut, removing .010" of stock. A subsequent, single finishing cut, removing .0005" from each stud, resulted in locational accuracy within

less than a "tenth," diametral tolerance of  $\pm .0001$ ", and a  $2\frac{1}{2}$  micro-inch finish. Total grinding time for four studs on each piece was 12 minutes, a significant improvement over any alternative method, yet productive of higher accuracy and better finish.

A thorough understanding of Jig Grinding principles is the best possible guide to the adaptability of the Jig Grinder to production jobs.

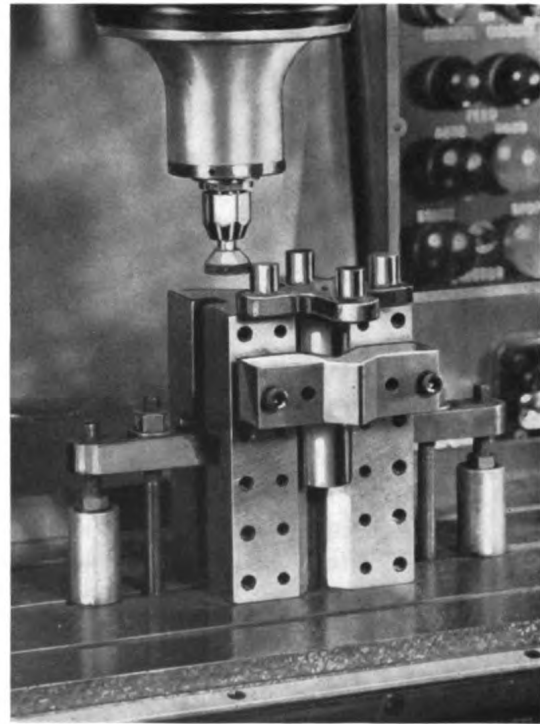


Fig. 207 — Jig Grinding four studs to size and location.

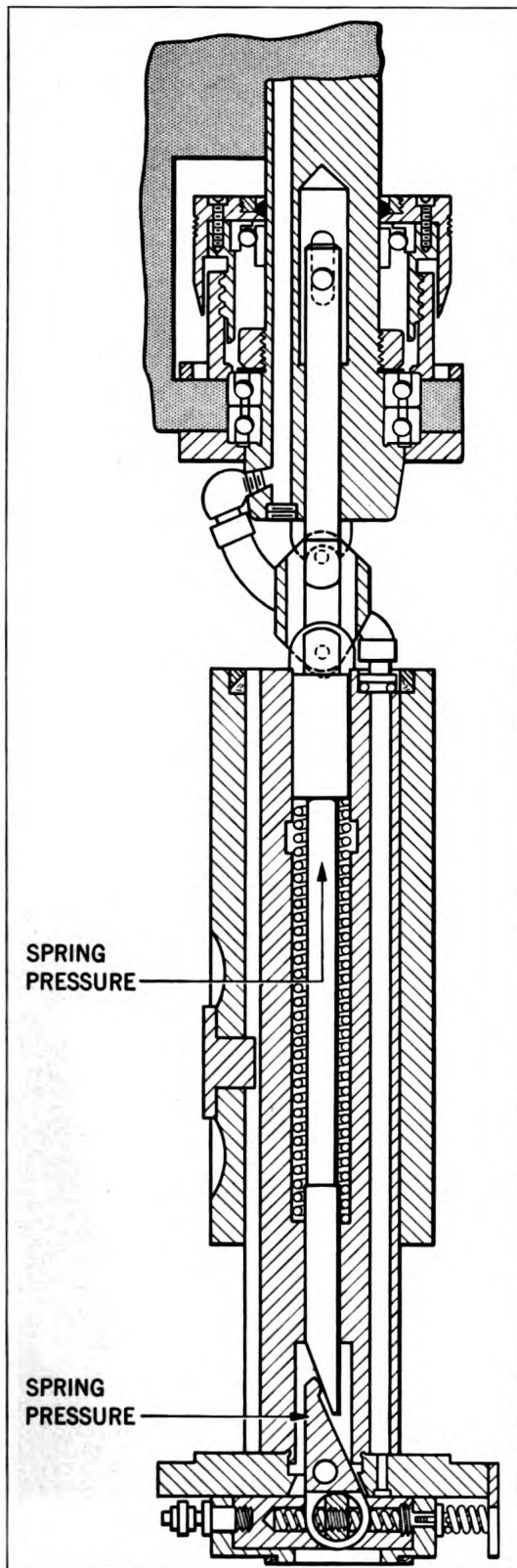
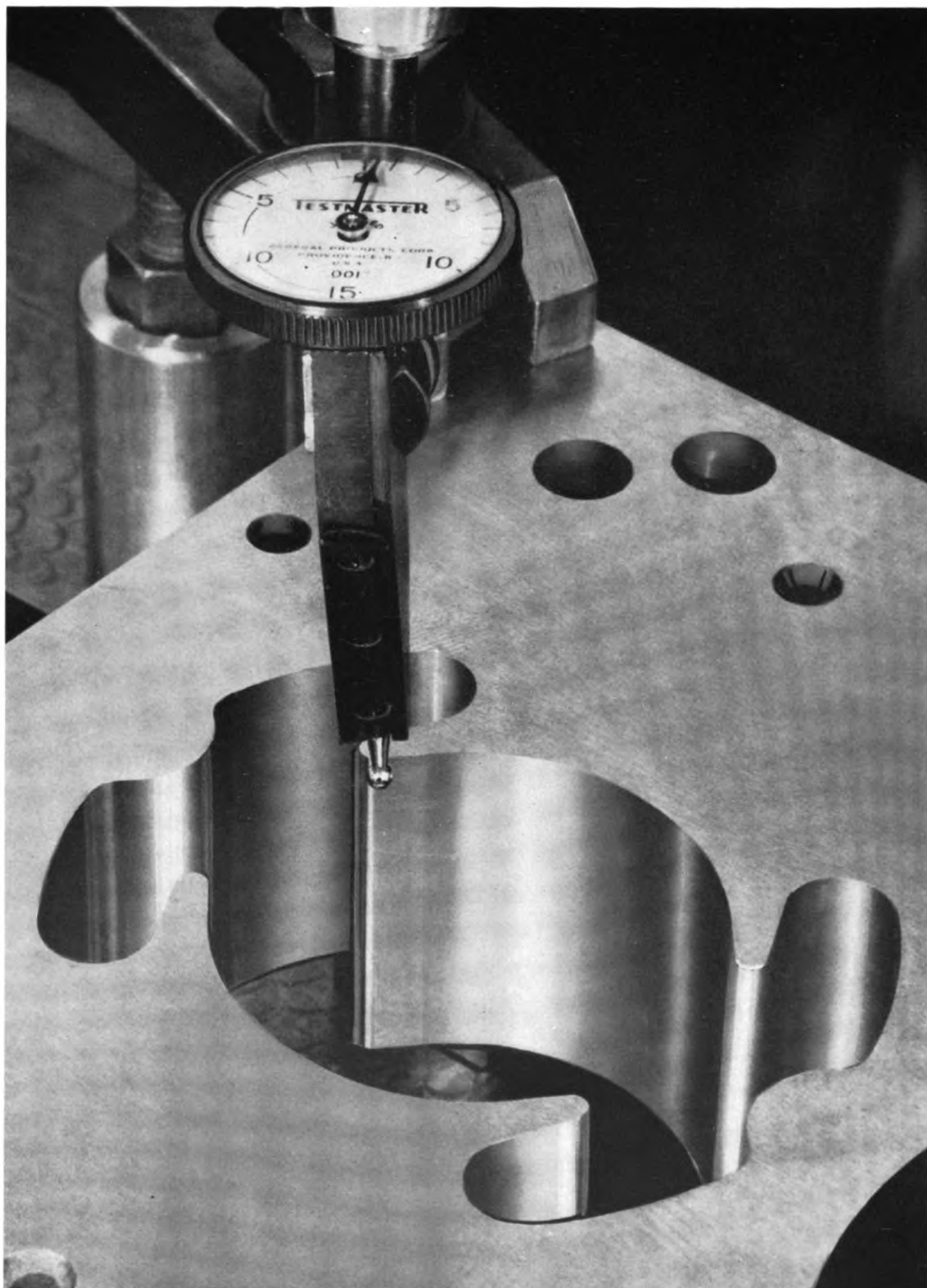


Fig. 209 — Possible failure of spring to overcome slide friction can be overcome by hand tapping grinding head when feeding.

**General Contour Practices** — Again, as in the case of the Jig Borer, the variety of work encountered in Jig Grinding precludes any detailed set of operating rules. The following general practices, however, will be helpful as a guide:

← Fig. 208 — Outfeed system employs spring return from limit of outfeed.



*Fig. 210 — An indicator is more accurate than visual methods of determining a blend between mating surfaces produced in different operations.*

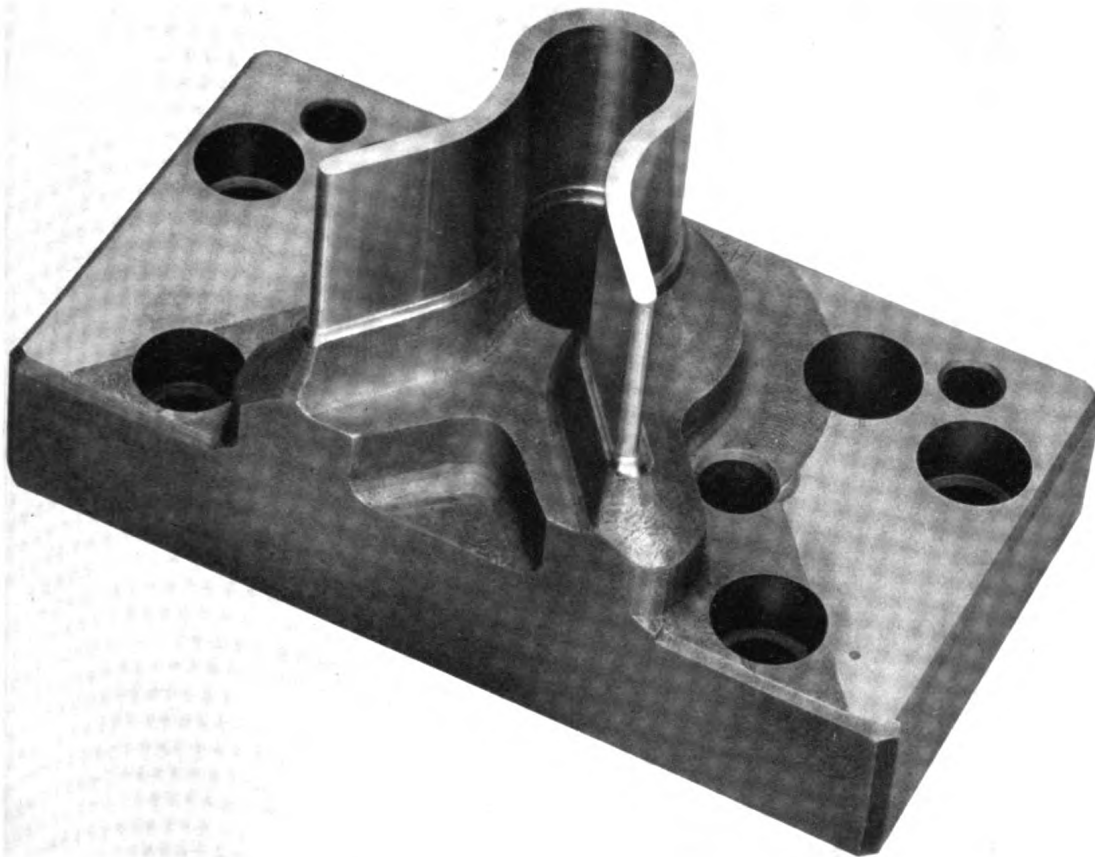


Fig. 211 — Previously described, this punch is classified as a “limited contour,” since the flange prevents linear grinding of its form.

1. Reference to Fig. 208 shows that while the outfeeding of a wheel is mechanically positive, infeeding depends upon spring pressure to move the slide. It is good practice, therefore, to tap the grinding head housing with the hand each time the feed dial is moved during infeeding to preclude sticking, Fig. 209.
2. The travel of the outfeed slide aligns accurately with the 0° and 180° graduations on the angle setting ring, Fig. 135, permitting alignment with cross slide travel.
3. Chop grinding is usually preferred for finishing some die contours, particularly mould and extrusion dies, since the grinding lines are in the desired direction.
4. Wipe grinding requires accurately cylindrical dressing of the wheel, because there is no vertical movement to eliminate reproduction of wheel inaccuracy on the work.
5. Attempts to remove more than about .0002" of stock per pass by wipe grinding is almost certain to burn the work.
6. Fig. 210 shows the use of an indicator as a more reliable means of determining the accuracy of a blend than visual inspection.

While enclosed contours are a “natural” for the Jig Grinder, and limited forms such as that shown in Fig. 211 can best be done on this machine, purely linear ones require a different machining method. This subject will be discussed in the following chapter.



*Linear Form Grinding Principles and Applications.*

## LINEAR FORM GRINDING PRINCIPLES AND APPLICATIONS

MODERN requirements of tool accuracy as the basis of production life and product quality necessitate more complete grinding of tools. This is particularly true in the case of die work. Here the relationship of punch, stripper, shedder and die must be carefully established to insure high production and product accuracy.

The simpler portions of such tools are invariably ground, because it is obviously easy as well as desirable to do so. Irregular por-

tions or contours, however, are often merely stoned or polished after hardening. This discrimination is not because such contours are functionally less important, but because they present such serious grinding problems.

In the case of enclosed or limited contours discussed in the preceding chapter, the solution lies in the contour grinding capabilities of the Jig Grinder. In the case of linear or open forms, the requirements dictate a different approach in search of a satisfactory solution.



Fig. 212 — A typical group of linear form-ground parts.

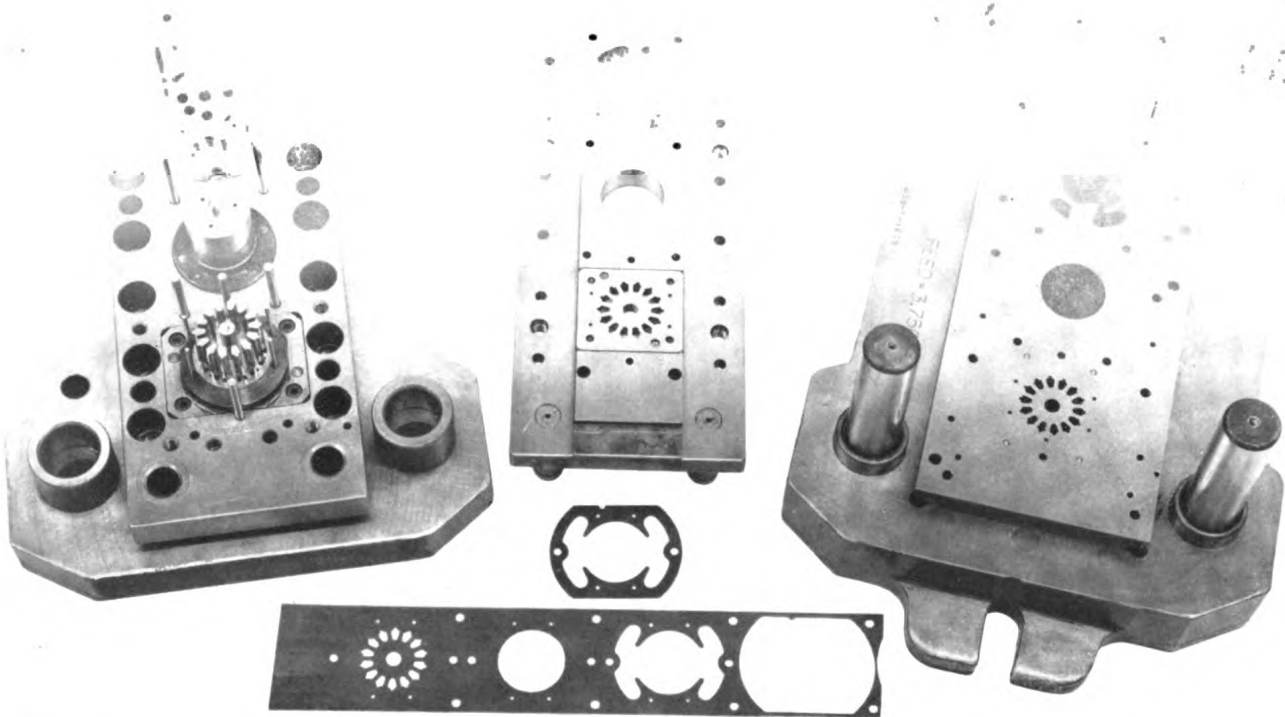


Fig. 213 — The previously described all-ground stator-rotor lamination die, accentuating the station containing linear form-ground parts.

Linear forms, typified by the heterogeneous assortment shown in Fig. 212, can be ground by a variety of methods, with widely varying degrees of efficiency and accuracy. Grinding such linear forms is obviously desirable and frequently, in view of the following factors, mandatory:

1. Considerable advantage, both to the toolmaker and the customer, can be gained from complete interchangeability. This is especially true in certain types of lamination dies, Fig. 213, where accurate form grinding makes all punches and all die sections in one station identical. This reduces assembly time by eliminating the need for selecting, stoning and fitting individual pieces, in spite of close clearance between punch and die.

Equally important is assurance that duplicate replacement parts, made to the same figures and therefore interchangeable, can be

provided in case of breakage. This service, often made necessary by a misfeed or other accident, is very valuable to the user of the tool.

2. As in the case of enclosed contours, tool life is greatly increased by uniformity of clearances and fits achieved through accurate grinding. Surface finish and hardness are improved. Full advantage can be derived from the quality and alloyed properties of the steel exposed by grinding, because of the softer, decarburized surface resulting from hardening.
3. Frequently, design and material selection are compromised to the detriment of strength and performance. Such a course results from the natural reluctance to tackle form grinding without sufficient familiarity with effective methods and equipment. Carbides and even the "hard-to-grind" steels are often avoided, even though they might be an ideal material choice, because they represent the ultimate in problems of linear form grinding.

## LINEAR FORM GRINDING PRINCIPLES AND APPLICATIONS

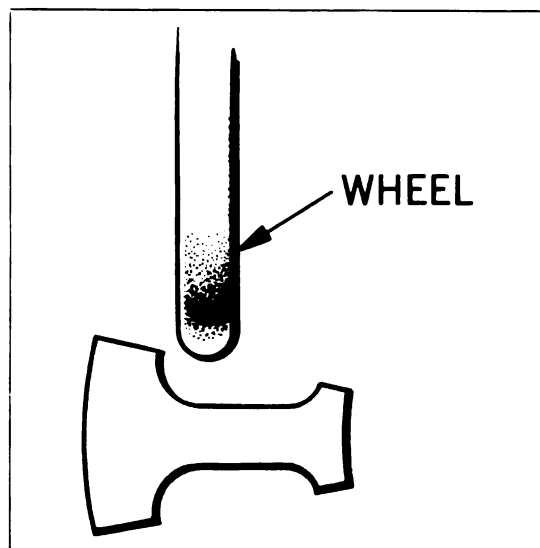


Fig. 214 — Forms are generated by relative movement between wheel and work.

4. In a number of instances, lack of “know-how” and attempts to grind linear forms on unsuitable or makeshift equipment have fostered false impressions as to the cost of this operation. As a matter of fact, the benefits from this practice amply justify the cost in all except the cheapest tools. Supporting this is the fact that efficient linear form-grinding equipment is so versatile that it generally can be kept in constant use even when not directly employed in form grinding. The cost of partially ground tools is sometimes used as proof of the greater cost of an all-ground tool. This may, in certain cases, be a valid comparison; but far more frequently the difference in cost is justified by increased quality, accuracy and service life.

*Increasingly keen competition is making the best tool the best investment. Only efficient contour and form-grinding facilities can produce the best tool at the lowest cost.*

In recognition of this fact, when confronted with problems of linear form grinding in its own contract toolroom, Moore undertook a survey and appraisal of available equipment and methods. The basic requirements included:

1. Versatility, to cope with the wide variety of typical jobs on a “one-at-a-time” or quantity basis.
2. Locational and dimensional accuracy compatible with contour Jig Grinding.

A grinding wheel produces forms by one of two methods, generation or duplication. Generation involves relative movement between wheel and work, Fig. 214. The shape of the wheel is unimportant, except that it will permit contact with the full surface of the form. The duplication method necessitates dressing a form on the wheel which will grind the required form in the work, Fig. 215.

As both methods have certain advantages for various types of work, a number of linear form-grinding devices have been developed around each system. Since a linear form is, in effect, an exposed surface, it is understandable that these developments should be closely related to the surface grinder, at least to the extent of the necessary relative movement between wheel and work.

**Generation of Form** — It is possible to generate a form on a conventional surface grinder, working to a scribed layout on the workpiece itself. In addition to the difficulty in making a sufficiently accurate layout, this method requires close manual coordination of cross and down feed while grinding. A means for an operator to observe a greatly magnified layout so that he could “see a tenth,” while manip-

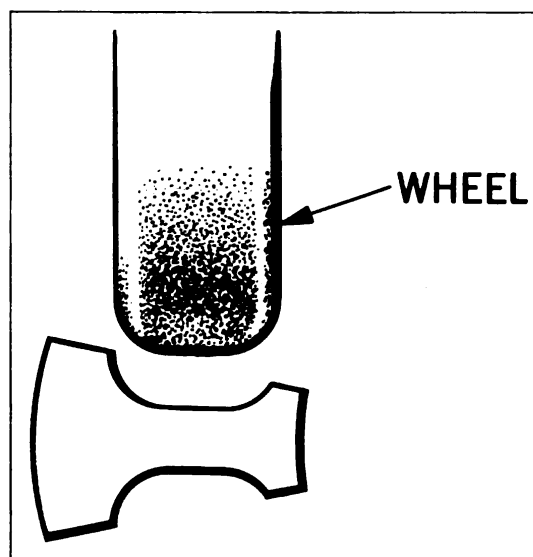


Fig. 215 — Matched form grinding requires dressing wheel to a shape that will produce the desired form on the work.

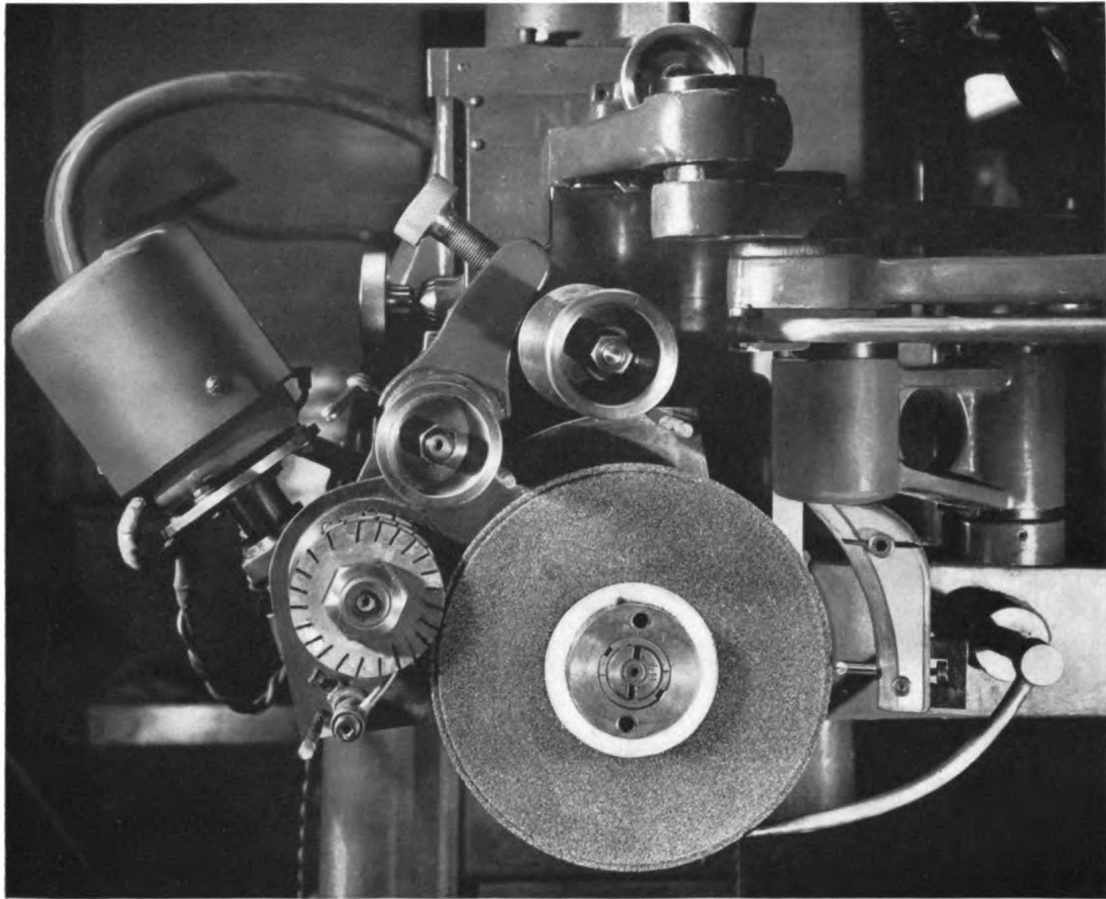


Fig. 216 — Form transferred from crusher roll to grinding wheel by slow, mutual rotation under contact pressure.

ulating the controls, would vastly improve the accuracy of this method.

Three variations of this principle of visual guidance are represented by the following form-grinding devices:

1. A magnifying optical projector is incorporated with a standard surface grinder. The optical system is mounted on the machine table so that, while the work is constantly in focus, the wheel is only intermittently so, as the table reciprocates. The ground surface is projected on a screen, which also carries a large-scale layout of the desired form. In operation, the work is ground until its form conforms to that of the layout on the screen. Multiple piece loads may be ground simultaneously, mounted end to end on the chuck. When not used for forms, such construction permits its use as an ordinary grinder.
2. A similar type, employing virtually the same

optical system, generates the form entirely by movement of the wheel.

3. A third variation differs in the type of visual guide presented. Contrasted with the "blown-up" layout and image of the work, this design provides the operator with a target of crossed lines in the optical field of a microscope as a guide. This microscope is located by a pantograph, from an enlarged layout of the desired form, and is successively re-positioned as necessary by aligning the stylus, or tracer, with the line of the layout. The contouring movement of the wheel is manually operated and the field of vision through the microscope is restricted to a small area. Grinding and movement of the target 'scope, therefore, must be accomplished by a series of incremental steps.

All three have a number of common characteristics:

1. Accuracy is dependent upon visual perception

## LINEAR FORM GRINDING PRINCIPLES AND APPLICATIONS

and coordination of manually controlled contouring movement while grinding. This requires a high degree of operator skill.

2. Contoured wheel form is unnecessary, an advantage in carbide grinding with a diamond wheel.
3. Grinding is accomplished by steps, thus making perfect blending difficult.
4. Difficulty in determining the coincidence of ground surface image and visual guide limits accuracy.
5. Flexibility of setup and movement makes possible grinding of a wide variety of complex forms.
6. Repetition of accuracy is difficult without a template or master. Each pass is, in effect, a new job.

Generation of form from a physical guide, such as a template, instead of a visual guide, provides a more positive system. By tracing the enlarged form of the template with a stylus, a pantograph linkage moves the wheel to produce the desired form in reduced scale on the work.

Features of this principle, contrasted with the visual guide system, include:

1. Greater assurance of repetition of accuracy, and less dependence on operator skill.
2. The wheel must conform to the shape of the stylus, with the same dimensional ratio as that of its pantograph linkage, a disadvantage when grinding carbide with diamond wheels.
3. Limited reciprocating stroke precludes multiple piece grinding.
4. A template is basically more accurate than a layout and provides an unchanging record, which can be re-used at a later date for duplication of parts.

**Matched Form Grinding** — Although all methods of linear form grinding involve a process of generation at some stage of the operation, the matched formed method differs greatly from the process of direct generation previously discussed.

In matched form grinding, the wheel is dressed to a shape which will produce the desired form on the work, Fig. 215. In effect, it functions as a form tool, contrasted with the similarity of a single-point tool to a wheel generating a contour. This analogy can be substantiated by pointing out that the same reasons governing the choice of a form tool

in preference to a single-point tool are equally applicable in the choice between generation and matched-contour methods of form grinding. These reasons include:

1. Greater accuracy of repetition.
2. Less dependence on operator skill.
3. Higher productivity.
4. Better finish from elimination of transverse feed across the form.

**Diamond vs. Crush Wheel Dressing** — The requisite form dressing of the wheel for matched form grinding can be had by generating the form with a diamond tool, or by crushing the wheel to shape. While the dressing action of a diamond is a familiar technique, the principle of *crushing* is uncommon enough to warrant a brief discussion.

A form turned on a steel or iron roll can be transferred to a grinding wheel by rotating one or the other slowly while bringing them into peripheral contact, Fig. 216. Increasing pressure of contact causes the bonding material of the wheel to crumble until the wheel

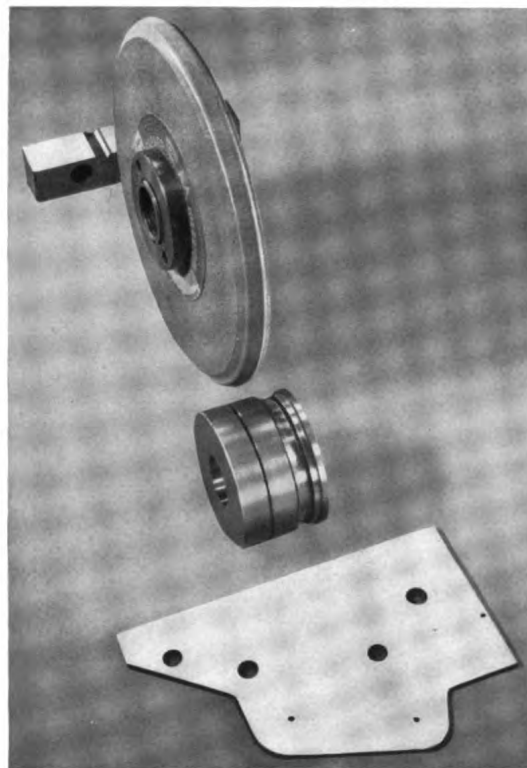


Fig. 217—Form on roll, wheel and work match each other.

conforms to the contour on the cylinder or crusher roll. Fig. 217 shows the relation of form between the template crusher roll, wheel and work. A variation of this technique employs a bar instead of a roll as the crushing element. A linear form on the bar can be transferred to the wheel of a surface grinder by mounting it on the chuck, parallel to the table travel. With the spindle motor off, and the table reciprocating, the wheel is slowly fed down to crush the form in the same way as with a roll.

Each method has its merits, which to a great extent complement each other. The more significant of these include:

1. Diamond-dressing produces highest accuracy and fidelity of contour, particularly in intricate forms. Crush-dressing permits sharper internal corners, Fig. 218.
  2. Diamond-dressed wheels produce the best surface finish. Crushed wheels grind more rapidly and stay cooler. These results are due to the shearing of abrasive grains by the diamond, so that they present a dull, flat face to the work. A crusher, by contrast, leaves the grains fragmented and sharp, but does not produce so geometrically accurate a surface, Fig. 219.
  3. Resinoid bonded wheels are too resilient to crush, and some vitrified wheels are so brittle that they shatter under crushing pressure.
- Used in combination, rough-grinding with

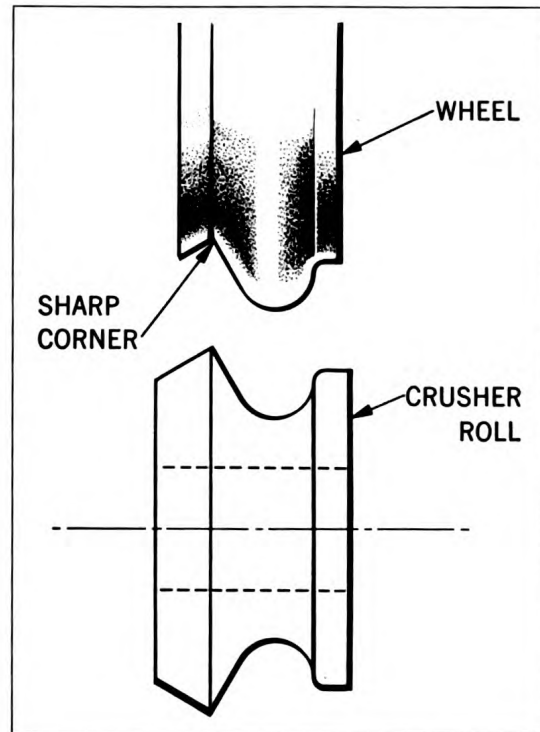


Fig. 218 — One advantage of crush-dressing is the ability to produce sharp internal corners on the work.

a crush-dressed wheel and finish-grinding with a diamond-dressed wheel, these methods offer advantages beyond the capabilities of either used alone.

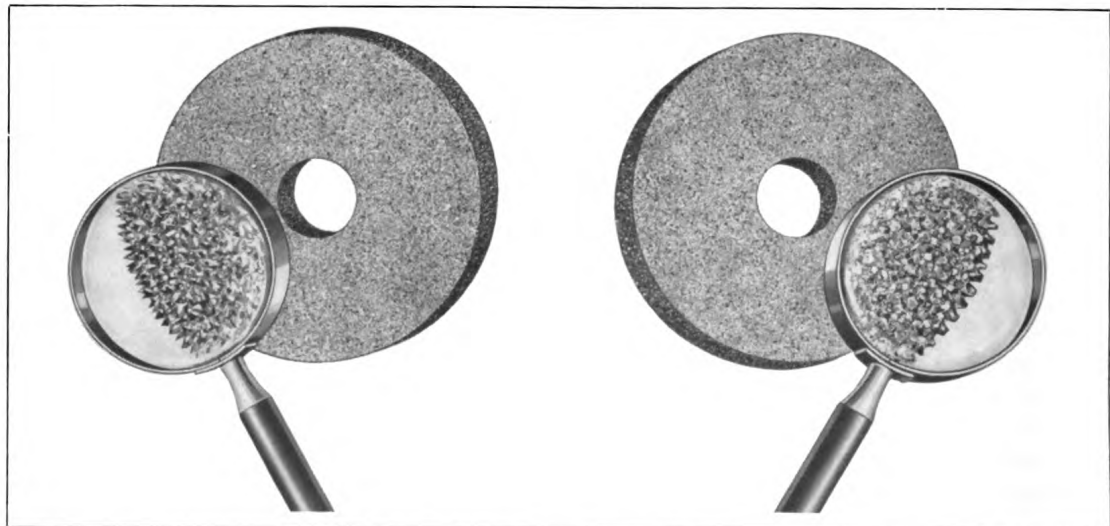


Fig. 219 — When magnified, the surface of a crush-dressed wheel is seen to consist of a series of sharp points; the surface of a diamond-dressed wheel consists of a series of flat plateaus.

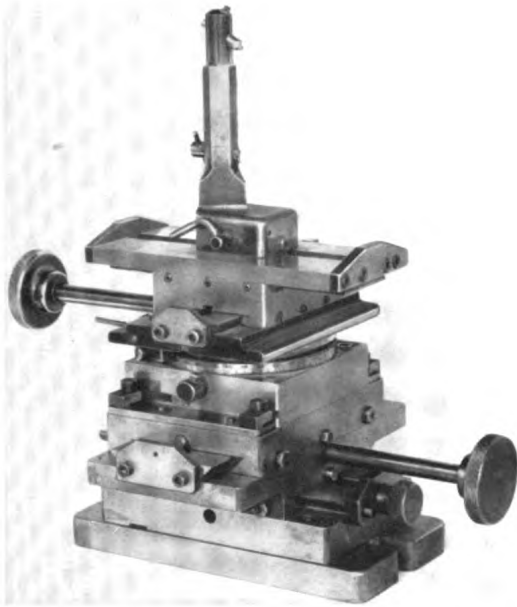


Fig. 220—The radius and tangent dresser is capable of dressing simple forms on a wheel. It provides two sets of rectilinear movement with a rotative motion possible between them.

**Diamond Form Dressing** — The simplest device for generating a form on a wheel, without the use of template, consists essentially of a diamond tool so mounted on an assembly of slides and rotating members that it can be swung through an arc and traversed along straight lines. These lines may be tangent or chordal to the radius produced, Fig. 220. The angular limits of the arc, its radius, the relationship of straight lines to the radius — are all controlled by the operator with the aid of graduations, size blocks or adjustable stops.

In operation, this device is set on the chuck of the machine with the center line of the wheel spindle in line with the diamond. The moves necessary to complete the form are successively performed by the operator. Low first cost is the outstanding advantage. It is possible to produce contours of considerable complexity with the more elaborate models having multiple compound slides and rotary movements. The simpler types are usually limited to relatively simple contours.

The greatest disadvantage in these dressers is the complete dependence on operator care and skill in making each move and setting; the element of risk and possibility of error, moreover, is re-introduced each time the wheel must be re-dressed. An additional risk, common to all chuck-mounted devices, enters the picture when it is necessary, as generally is the case, to remove the work load in order to dress or re-dress the wheel. Here the problem is to orient the dresser to the existing contour on the wheel; and later, to reorient the workpiece with the contour on the wheel.

The use of a template or master as a guide for a stylus which, in turn, moves the diamond to dress the wheel, minimizes greatly the effect of the human element in this operation.

One device in which the stylus moves the diamond in a 1:1 ratio is shown in Fig. 221. In use, the stylus is first matched to the diamond by laying the tool on its back, Fig. 222. The diamond is slowly fed into the wheel by movement of the grinder table until it has dressed a groove exactly conforming to its own profile. The stylus is then fed through the wheel, and thus ground to the same outline.

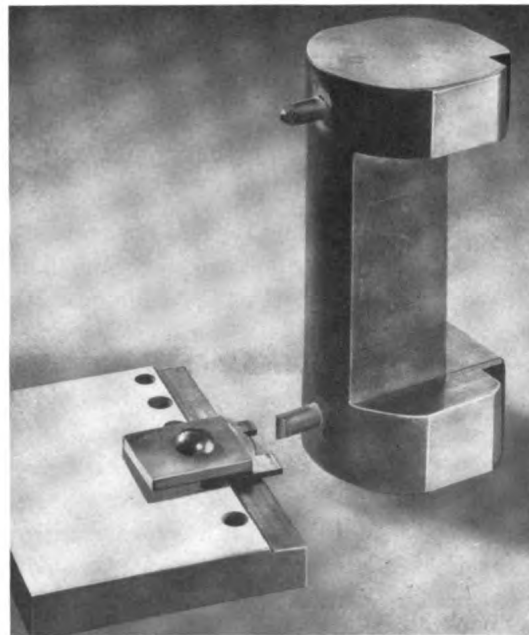


Fig. 221—This simple copy-dressing device has many uses.

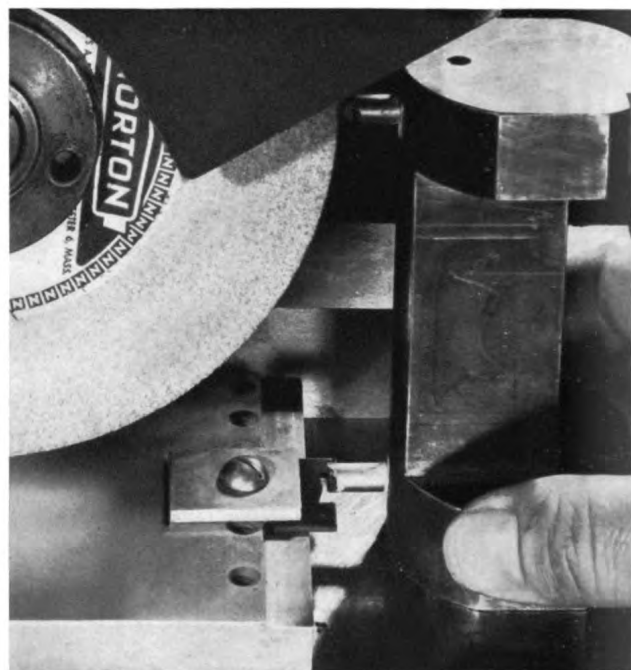
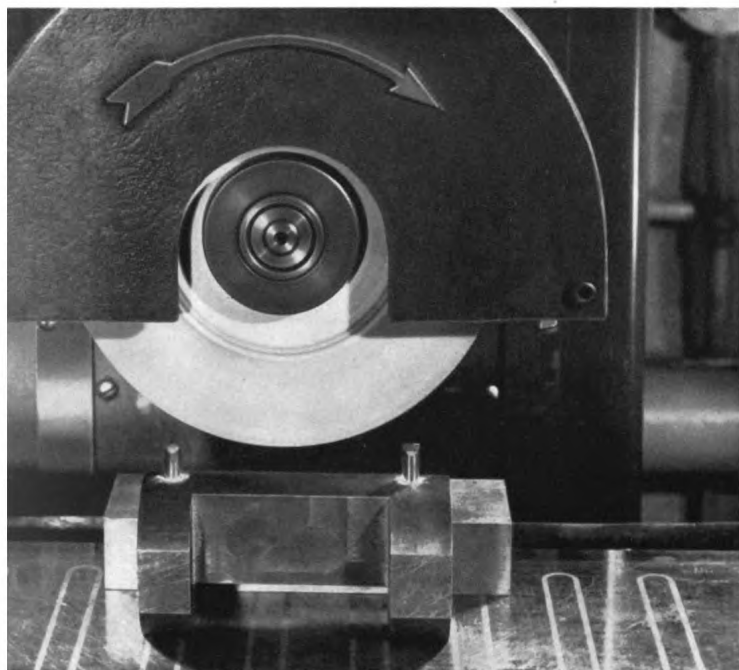


Fig. 222 — This type of dresser is capable of matching its own diamond and 1:1 stylus.

By locating the template on the chuck and following its contour with the stylus, a matching wheel shape is produced. Besides ability to match its own stylus to the diamond, the one-to-one ratio has another advantage: It is possible to reproduce an existing workpiece or sample by using it as a first template from which the wheel is dressed to grind a second template. The form on the second piece will be the reverse, so it can become a template for grinding a duplicate of the original.

This type of dresser has the virtues of low cost, a degree of flexibility and convenience, relatively little dependence on operator skill, plus reasonable accuracy of repetition. However, in addition to a limitation of accuracy due to its one-to-one ratio, it shares disadvantages common to all chuck-mounted equipment.

An elaboration of the basic concept provides a supporting bracket for the dresser. This improvement permits freedom of movement during dressing and keeps the chuck clear, except when the stylus is being matched to the diamond.

This appraisal of various form-grinding

methods and devices revealed that none incorporated *all* of the features necessary to equal, in linear forms, the accuracy and efficiency of the Jig Grinder in grinding enclosed contours.

**Diamond and Crush Dressing Combined —** In order to fulfill this requirement, the Moore Panto-Crush Wheel Dresser, Fig. 223, was developed. Designed as a permanent attachment to the spindle housing of a surface grinder, this device form-dresses the wheel from a template, through a 10:1 pantograph linkage. As the Panto-Crush name implies, it provides an alternative crush-dressing means and the interchangeable use of either method.

In operation, the template form is transferred to the wheel, by diamond-dressing, through the pantograph. This form, in turn, is ground on the circumference of the motor-driven crusher roll as it is fed into the wheel, Fig. 224. The average form can thus be accurately produced on a blank crusher roll in fifteen minutes.

Advantages offered by this combination of crush-forming and diamond-dressing in a single unit include:

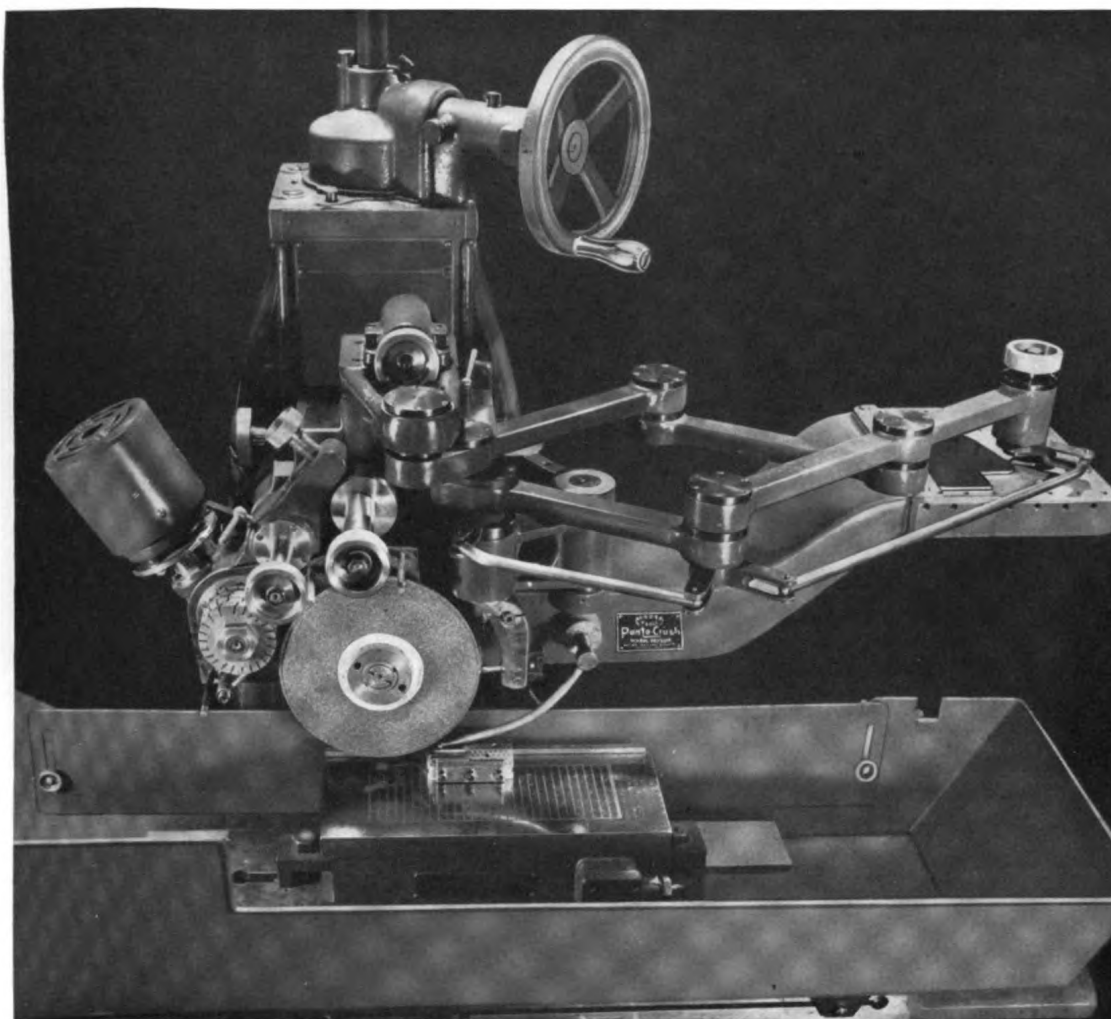


Fig. 223 — The Moore Panto-Crush Wheel Dresser combines diamond and crush dressing from a template.

1. Either method is immediately available for any given job.
2. Necessary re-dressing of the wheel becomes a simple, repetitive operation with either method.
3. Irregular contours may be generated in a continuous pass of the diamond — impossible with the radius-tangent type dresser.
4. Maximum economy and accuracy are achieved in making and using crusher rolls.
5. Switching from one method to the other, at any stage of grinding, in no way alters the locational relationship of the form on template, wheel, crusher roll or workpiece.
6. Raising or lowering the wheel spindle does not alter this relationship.
7. Full advantage of the cooler, fast-grinding action of a crush-dressed wheel for roughing is combined with the highest accuracy and finish produced by the diamond-dressed wheel used for the finishing grind.
8. Diamond-charged wheels can be contoured easily to grind linear forms in carbide.

In addition to the conventional panto-graph movement, the diamond and stylus are linked together for mutual angular rotation. This makes possible the dressing of otherwise inaccessible portions of a form by changing the relative angle of diamond to wheel surface, Fig. 225. The choice of a radius, as the strongest shape for diamond and stylus, permits wear to be evenly distributed by this same angular rotation, Fig. 226.

The inherent soundness of concept and

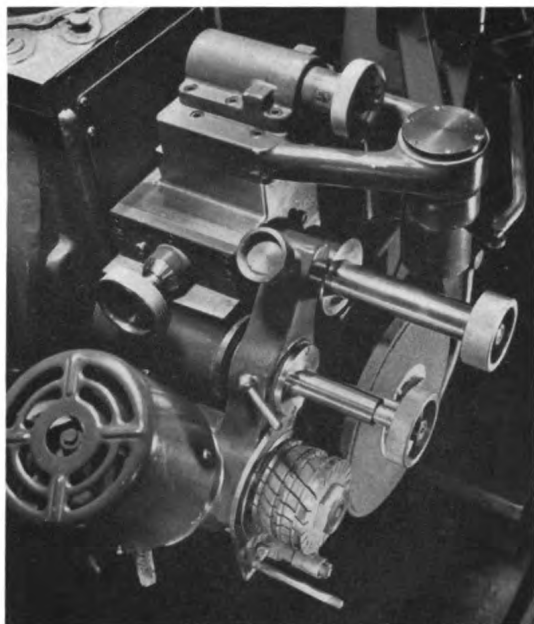


Fig. 224 — The average form can be ground into a hardened crusher roll blank in about 15 minutes.

design of this device is attested to by its acceptance in hundreds of installations. One conclusion, however, is inescapable: *In the case of any dressing device attached to a surface grinder, a certain portion of the responsibility for accuracy of the product rests with the grinder itself.* The obvious remedy lay in the development of a complete form-grinding machine, incorporating the features of the Panto-Crush principle with a grinder designed to take full advantage of the method's wheel-dressing accuracy. The result of this combination is the Moore Form Grinder, Fig. 227.

Geometric accuracy of this machine is insured by the same general means as outlined in Chapter 4. Its linear accuracy, incorporated in the cross feed screw, is comparable to that of the Jig Borer, in order to position forms precisely or relate portions of forms, Fig. 228. General considerations incorporated in the design include:

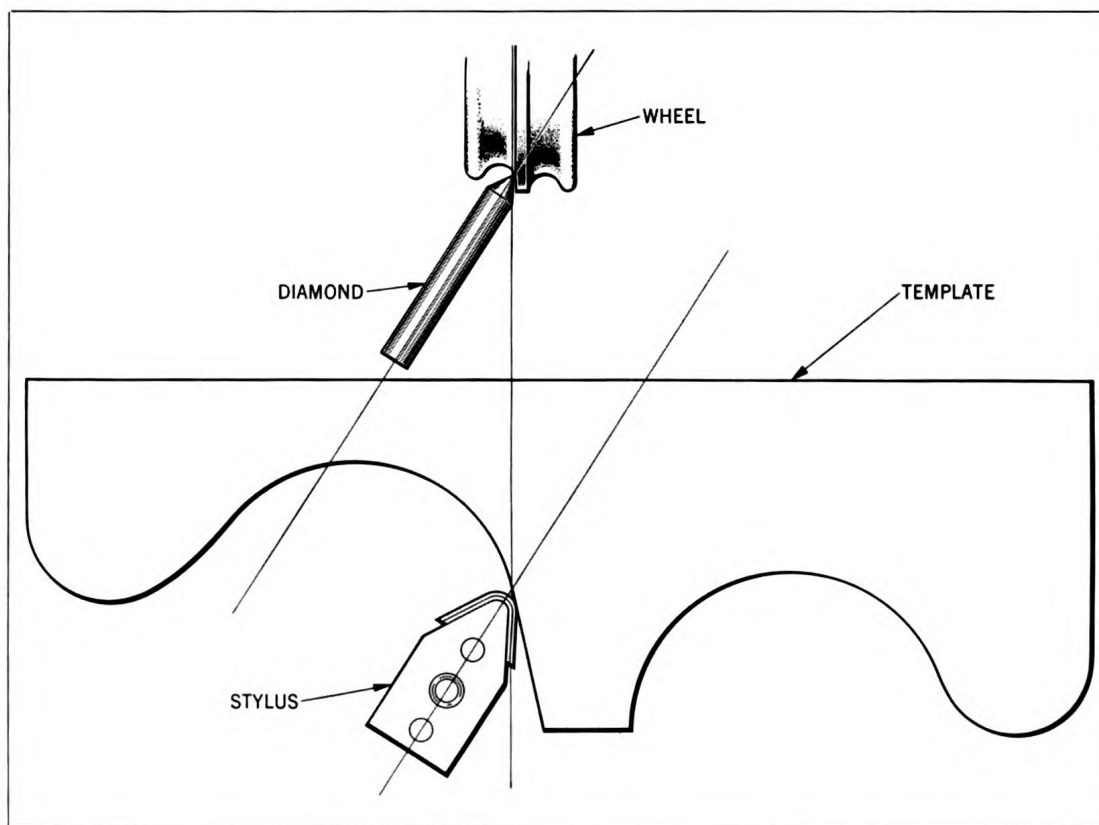


Fig. 225 — Presenting the diamond to wheel at an angle facilitates dressing of certain forms.

## LINEAR FORM GRINDING PRINCIPLES AND APPLICATIONS

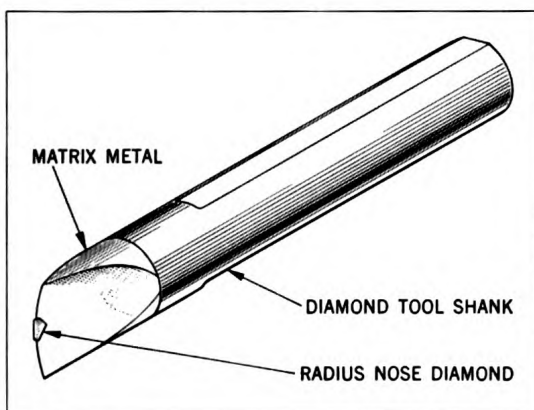


Fig. 226 — Accurately radiused diamond combines strength and wear resistance.

1. Accuracy of alignment of feeds and travels.
2. Anti-friction spindle, for accuracy and rigidity.
3. A non-influencing clamping means, for locking the cross travel during form grinding.
4. Elimination of axial spindle movement as a result of temperature variation.

The prototype pantograph linkage was re-designed to increase range, accuracy and convenience, without sacrifice of any of the original features. The crusher roll support was stiffened by mounting it on the table of the machine.

These features give the Form Grinder the following advantages:

1. Movement of the stylus in tracing template forms is reproduced in a reduced movement of the diamond in a ratio of 10:1. This offers a high degree of accuracy in dressing from a template which itself need not be precise. An error of .001" on the template is reduced to .0001" on the work.
2. With the 10:1 ratio relatively wide forms can be dressed without necessitating inconveniently large templates.
3. Operator skill requirement is held to a minimum.
4. Thanks to a permanent master, the template, exact duplicates can be made at any future time.
5. Dressing forms slightly larger or smaller than 1/10 template size needs only a simple adjustment of the diamond. A two-stage roughing and finishing operation, or a shedder and punch, or a blanking and shaving die, can be ground in this way from the same template.

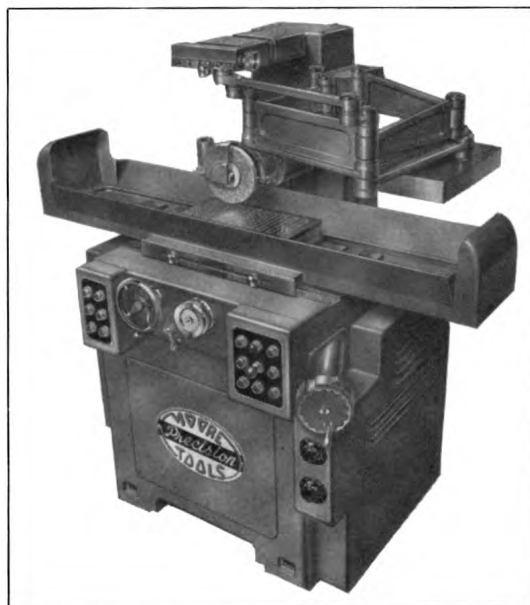


Fig. 227 — The dressing and grinding elements of the Moore Form Grinder complement each other.

6. It is equally suited to "one-at-a-time" or production grinding of either linear forms or flat surfaces.
7. Variable stroke and feed rates permit normal traverse grinding or plunge form grinding.
8. The grinding and dressing portions of the machine are designed for each other.

This comparison of alternative linear form-grinding methods, together with a background of the principles involved should provide a firm foundation for discussing in the following chapters the practices found to produce maximum accuracy and efficiency.

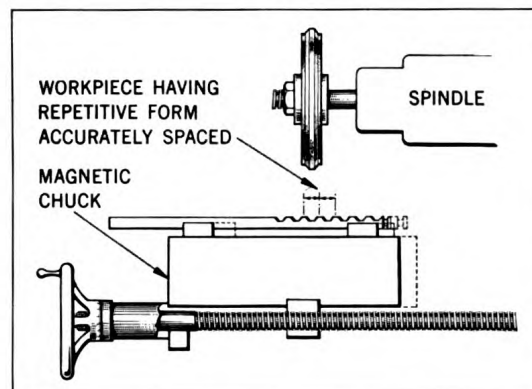
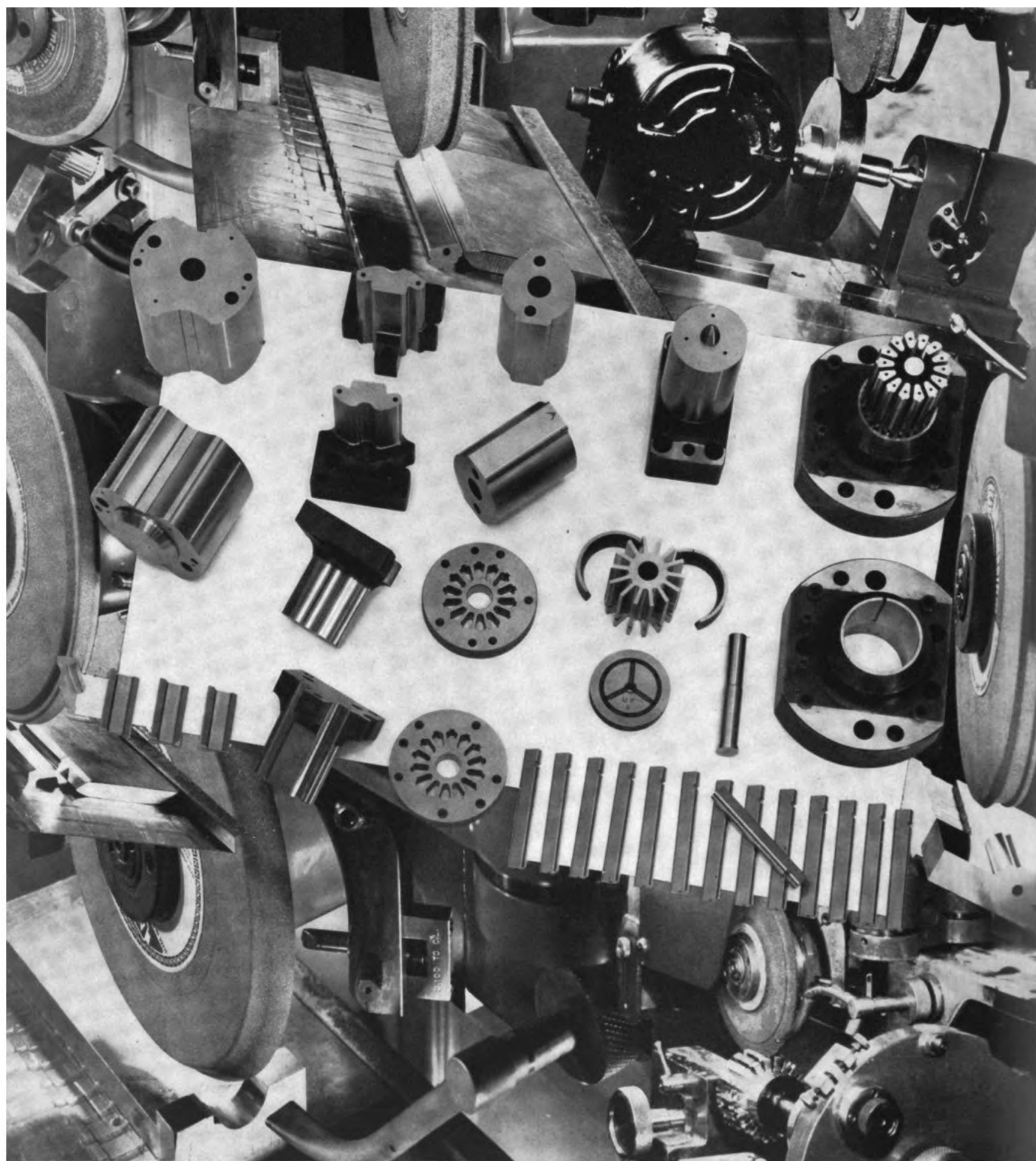


Fig. 228 — An accurate cross feed screw is important in uniformly spacing forms.



*Linear Form Grinding Practices.*

## LINEAR FORM GRINDING PRACTICES

A WIDE variety of workpieces can be ground on the linear Form Grinding machine. Not only must purely linear forms be considered, but circular forms, indexed forms and a variety of minor variations, each of which requires its own special "know-how."

The following outline of recommended operating practices does not represent the only way to do the job; it represents a summary of practices found most satisfactory in Moore's and other leading toolrooms.

**Setting up the Workpiece** — Linear forms must be ground on such a wide variety of workpiece shapes that a certain amount of improvisation enters into most setup operations. This generally involves little more than a special set-edge or simple holding block, although for more exacting requirements and complicated shapes a fairly elaborate fixture may be necessary. The most universally convenient setup device for the general run of linear forms is the inclinable magnetic chuck, Fig. 229, which can be accurately set to the required angle by means of size blocks by the sine bar principle.

Forms may be ground at angular divisions of the circle from the index plate of the Moore Motorized Centers, Fig. 230. This accessory is also convenient for cylindrical form and taper grinding, as well as for a variety of otherwise difficult grinding jobs, Fig. 231. Higher angular indexing accuracy and greater capacity are available in the index fixture, Fig. 232,

developed especially to meet linear form-grinding requirements.

**Dimensional Pickup of Workpiece** — As described in Chapter 11, the locational relationship of form on template, wheel and work is constant. Therefore, cross movement of the machine table is used to bring the form on the wheel into proper relation to the set-edge or locator against which the reference point of the work registers, after which it is clamped. This pickup can be determined by mechanical measurement or by use of an optical projector. Thus positioned, one piece after another, or successive chuck loads, can be ground in the same location.

Similarly, the position of the form can be established in any setup, whether it be on a chuck, motorized centers, index fixture or special holding device.

**Template-Making** — Although it can be made by the layout, bandsaw and file method, it is generally unwise to use up so much of the final workpiece tolerance in the template. Also, no more time is taken to make the template accurately with the proper equipment. In this way, the operator may take advantage of whatever leeway is permissible in the more exacting job of form grinding.

The Jig Borer has proved to be the best source of accuracy and convenience in template-making, Fig. 233. If only radii and rectangularly related surfaces are required on the template, the blank of  $\frac{1}{8}$ " brass can be

## HOLES, CONTOURS AND SURFACES

set up on the machine table. If, however, angular relations must be established, the blank is set up on a rotary table.

Using conventional Jig Borer practices, female radii can be machined, resorting to indicator measuring for size determination where necessary (page 140). Male radii are located by a small construction hole, which is used to center this point by means of an indicator over the center of table rotation. Using a cutter of known diameter and moving the machine table the requisite amount to correctly relate the spindle axis and rotary table axis, Fig. 234, male radii may be machined by rotating the table through the required arc. Thus, in general, ordinary Jig Boring practices permit the complete machining of even the most complex templates accurately and efficiently.

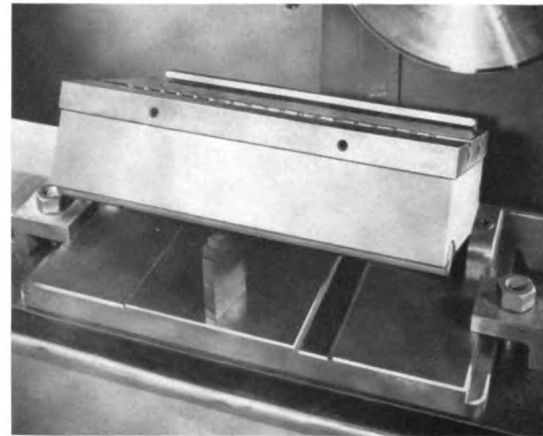


Fig. 229 — Inclinable magnetic chuck is invaluable in linear form grinding.

Some research has been initiated in the field of producing the second of a matching pair of templates, required for punch and die,

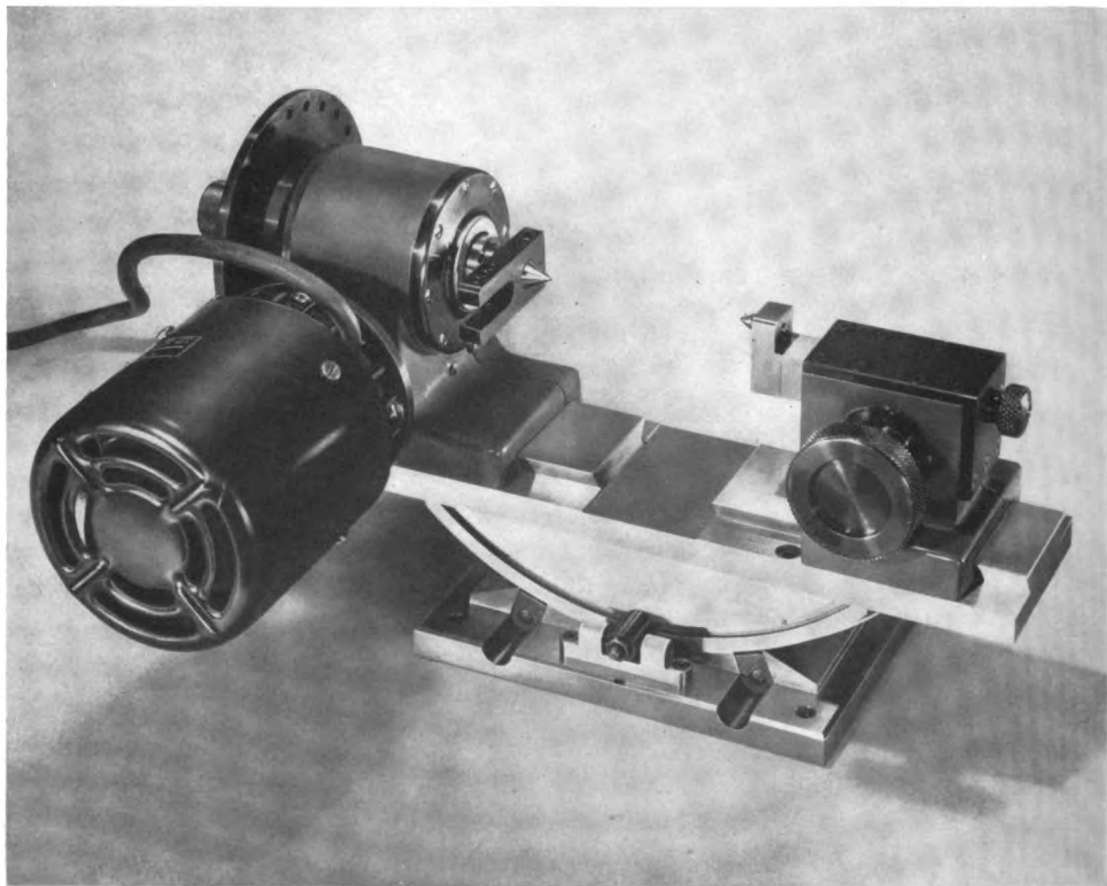


Fig. 230 — Moore Motorized Centers can be effectively used in a variety of grinding jobs.

## LINEAR FORM GRINDING PRACTICES

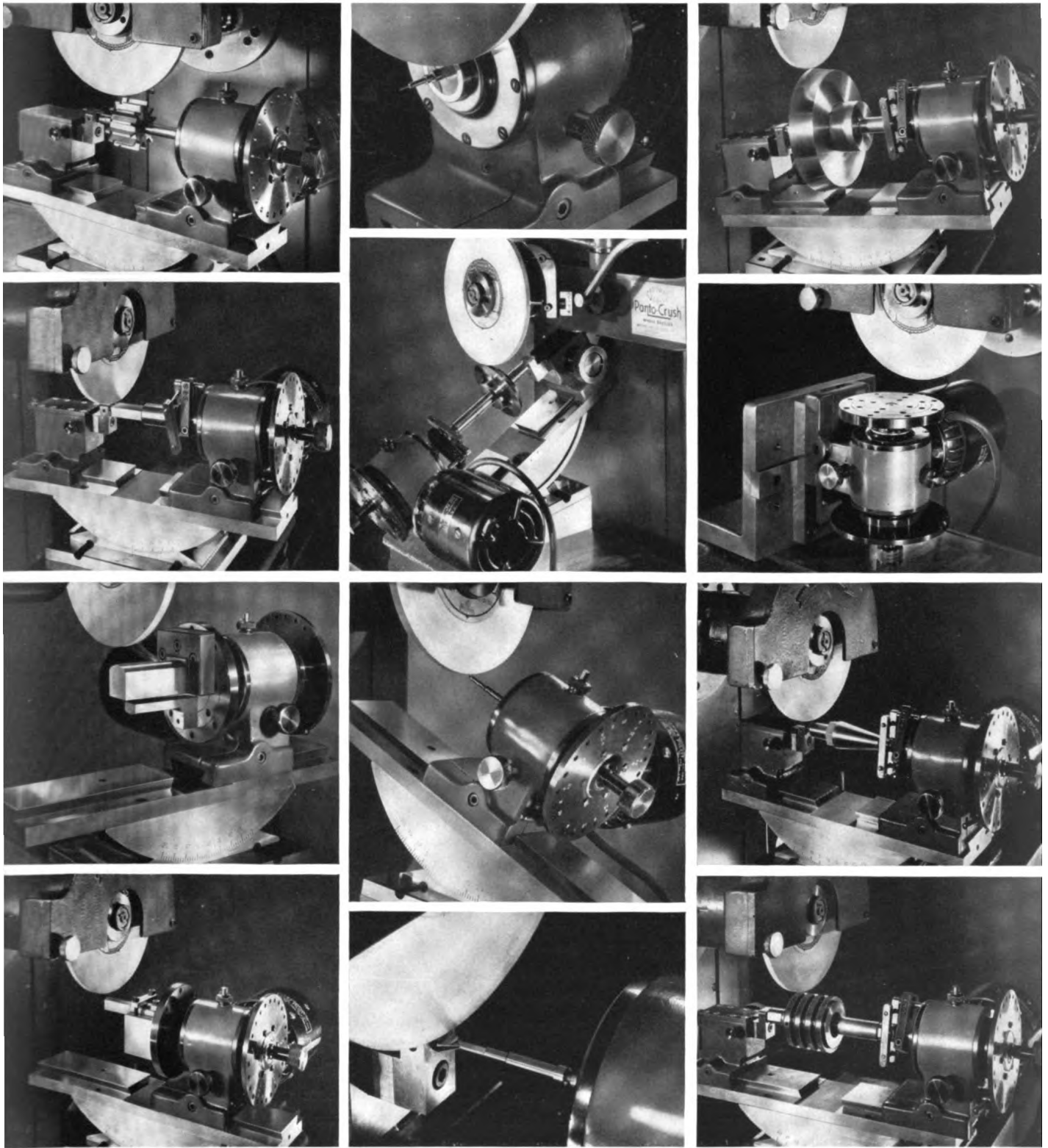


Fig. 231 — Some of the many uses of the Motorized Centers.

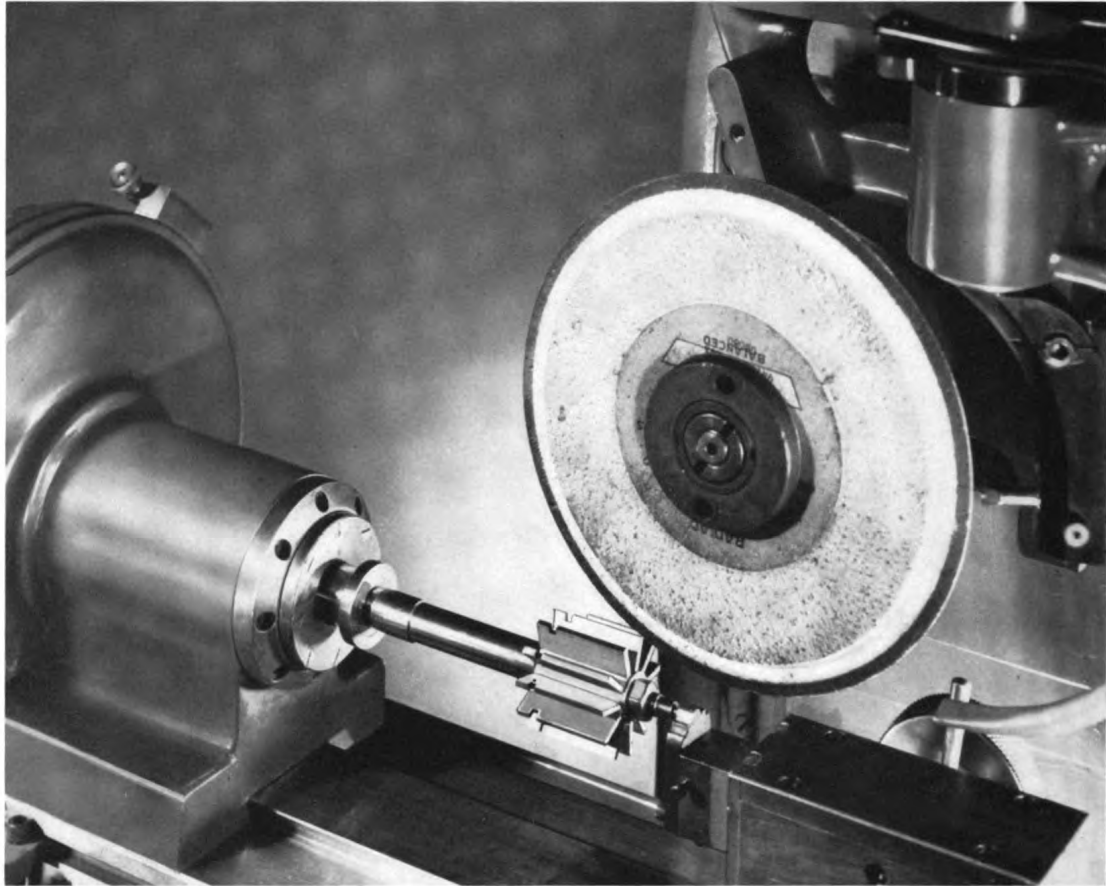


Fig. 232 — The Moore Horizontal Index Fixture meets the need for high accuracy of index spacing frequently required in form grinding.

by casting: For example, there is the possibility of producing a matching template without machining, by allowing molten sulfur to solidify against the contoured edge of the machined template. To date, this method has shown some promise; it has not been an unqualified success.

In order to avoid foreign matter, such as abrasive dust, crowding between template and stylus, it is good practice to slightly chamfer the *lower* edge of the template contour, Fig. 235. This insures metal-to-metal contact between the two members.

**Wheel Choice** — Wheel choice directly affects rate of stock removal, surface finish and diamond life. The choice of a suitable wheel should be made with these factors in mind. Frequently it will be a compromise.

High-carbon, high-chrome and high-speed steels present a problem of wheel choice in any type of grinding, particularly in linear form grinding. The most satisfactory abrasive for these steels appears to be silicon carbide in wheels of J hardness. An 80-grit wheel provides a very satisfactory rate of stock removal. Finish-grinding, with its requirement of good surface finish, benefits from the use of a finer wheel of approximately 120 grit.

Although wheel specifications are presumably standardized, there is an observable difference in performance between wheels supplied by different manufacturers. It is, therefore, advisable to make a performance comparison before final selection.

Coolant should always be used with this type of wheel when grinding the abrasive-



*Fig. 233 — Machining a template of clock brass on No. 2 Jig Borer.*

resistant types of steel. Wheel speed is fairly critical, optimum conditions being reached at 3,000 rpm for a 7" diameter wheel.

The easier grinding types of steel present no

serious challenge to a wheel. A satisfactory choice can be made from the inventory of wheels ordinarily used for surface-grinding the same material.

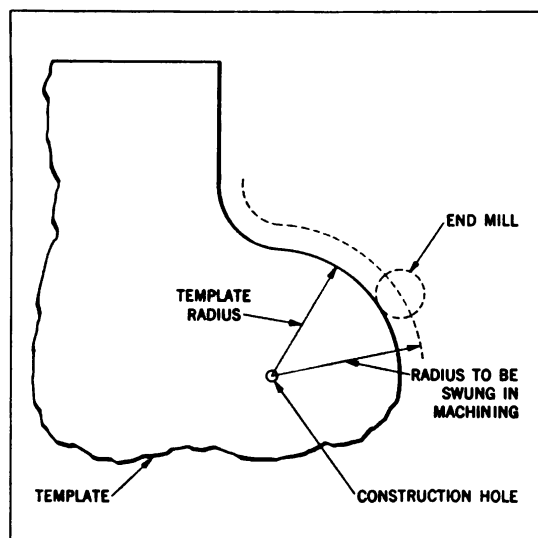


Fig. 234 — Relation of spindle axis, cutter and rotary table in machining templates on a Jig Borer.

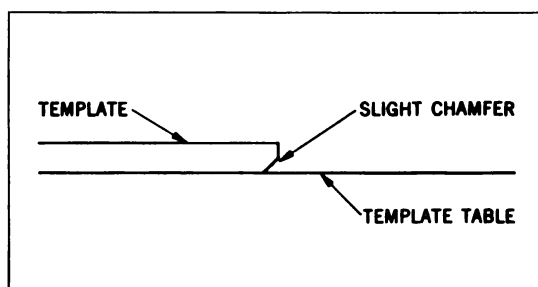


Fig. 235 — Chamfering lower edge of template contour insures good contact with stylus.

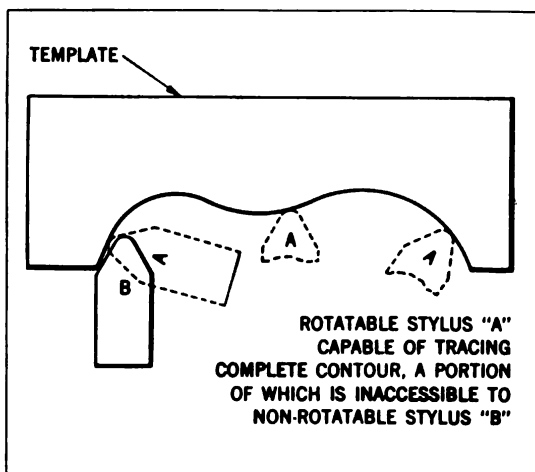


Fig. 236 — Fixed angle diamond cannot dress many forms.

Form-grinding of carbides introduces an entirely different wheel concept and grinding technique. This will be discussed later in the chapter.

**Wheel Dressing** — As explained in Chapter 11, the related angular articulation of stylus and diamond permits dressing forms which would be impractical, were it necessary to keep the diamond normal to the wheel spindle, Fig. 236. In order to accomplish this without reducing the accuracy of the 10:1 pantograph mechanism, it is important that the center of radii of both the diamond and the stylus be exactly in line with their respective centers of rotation, Fig. 237.

This condition is attained automatically in the stylus by the locating dowels in the arm to which it attaches and the Jig Ground dowel holes in the stylus itself. The lateral centrality of diamond radius is insured by the accuracy of its generation from the shank, in diamonds supplied direct from Moore. This shank, in turn, locates precisely in a carbide bushing in the diamond arm, Fig. 238.

Longitudinal positioning of the diamond is accomplished by measurement from the gaging bridge, Fig. 239, using a micrometer caliper. The dimension etched on the bridge is from the gaging surface to the center of rotation of the supporting arm. In measuring over the nose of the diamond, its radius must be added to this value.

Diamonds and corresponding styli are available in the following sizes:

#### 60° SERIES

Diamond Tool	Corresponding Stylus
.005"	.050"
.0075"	.075"
.010"	.100"
.0125"	.125"
.015"	.150"
	.200"

Worn diamonds, if not abused, may be re-dressed to a larger radius; thus the .015" diamond would be restored to match the .200" stylus.

To avoid excessive diamond wear, some roughing of the form on a wheel may be done

## LINEAR FORM GRINDING PRACTICES

with a hand-held carborundum stone. Final roughing to the template form should be accomplished with the special roughing diamonds available.

Final dressing should be carefully done, so that a minimum of stock is removed from the wheel with each pass of the diamond. This should not exceed .001" with diamonds down to .010" radius, and only a few "tenths" with smaller diamonds. In this way, both the diamond and the wheel will last longer.

Diamond life and surface finish will both benefit from the selection of the *largest* diamond for dressing of the *smallest* radius in the required form.

Frequently the requirement will arise for grinding a linear form in two slightly different sizes. Typical examples include:

1. Roughing and finishing the same form.
2. Blanking and shaving stations in the same die.
3. Shedder and punch.

This dimensional variation of the same form may be achieved with a single template by these alternative methods:

1. Where the desired dimensional difference is .001" or less, the diamond can be advanced or retracted from normal position in relation to the center of rotation of the diamond arm. Advancing the diamond produces a form larger than 1/10 that of the template, by the exact amount of its increased projection. Conversely, retracting it produces a smaller form. This method imposes the requirement of keeping the diamond normal to the wheel spindle, avoiding any angular rotation of diamond and connected stylus.
2. Where a dimensional difference of form up to .003" and/or greater insurance of accuracy is desired, the nominal 10:1 relationship of stylus to diamond is altered. For example, should a form .0025" smaller than that normally produced from a template be required, a .125" stylus can be used with a .010" diamond. To produce a larger form than nominal the procedure is reversed: A .075" stylus would be used with the .010" diamond. With this method, angular movement of diamond and stylus, so necessary in dressing many forms, is possible.

Having dressed a form on the wheel, it is advisable to check it before grinding. A con-

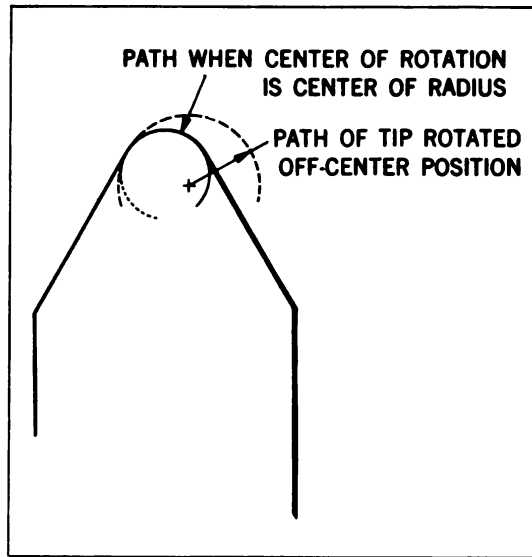


Fig. 237 — Off-center diamond can cause error in form.

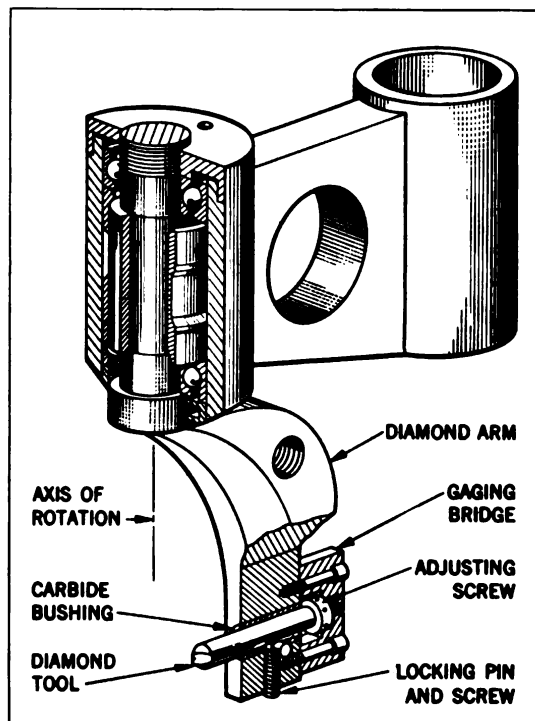


Fig. 238 — Carbide bushing and non-influencing lock pin accurately position diamond.

venient means of doing this is to set up a piece of sheet plastic, such as bakelite, and take a trial cut through it with the wheel, Fig. 240. This piece may now be compared with a lay-



Fig. 239 — Diamond is longitudinally positioned to micrometer measurement from gaging point.

out in an optical projector, before grinding the workpiece.

**Form Grinding** — The all-ground lamination die, Fig. 241, one station of which has served as an example of enclosed contour Jig Grinding, also provides in its rotor-piercing station, Fig. 242, a typical example of linear form grinding. In order to illustrate sound form-grinding practices, this operation will be outlined, step by step, as applied to the accurate and interchangeable punches and die sections, Fig. 243, of this press tool.

The punches are form-ground from rectangular, hardened blanks as follows:

1. The blank is mounted on a magnetic chuck,

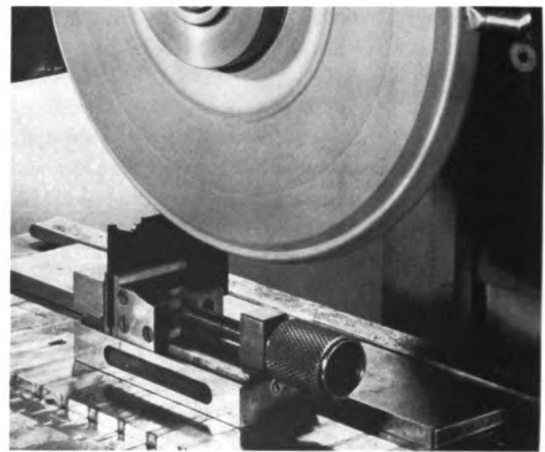


Fig. 240 — Trial grind of form in plastic test piece.

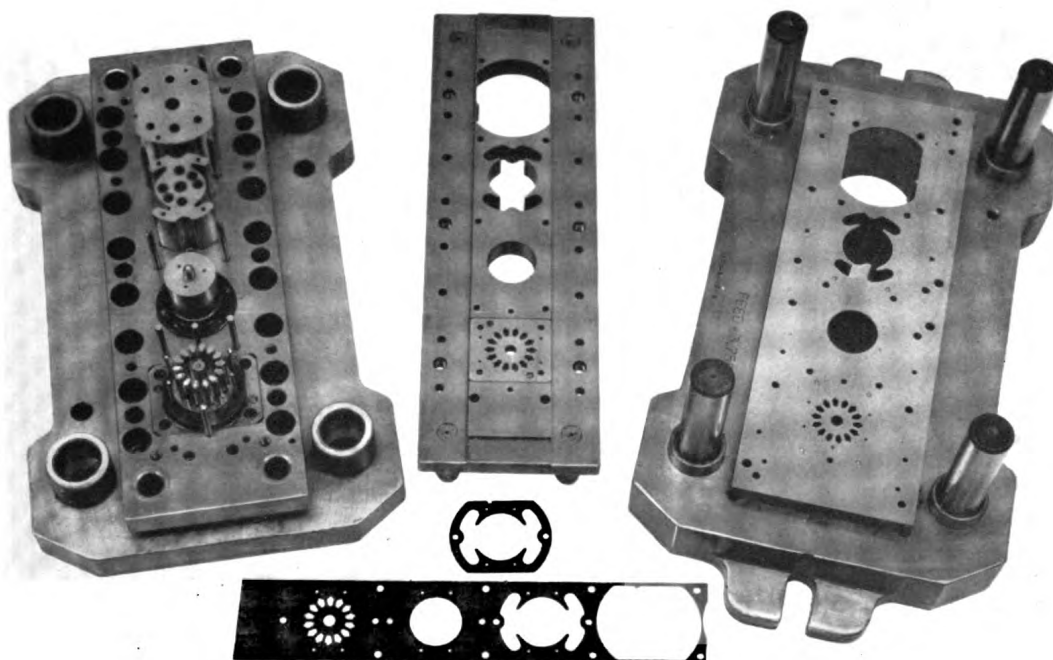


Fig. 241 — In the interest of continuity, this same all-ground stator-rotor lamination die will be used to illustrate the technique of linear form grinding, and its relationship to the location of holes and contours.

and the form is rough-ground on one side, Fig. 244. By using a smaller stylus than normal (see page 179), the wheel can be dressed so that this rough form-grinding leaves .002" for subsequent finish form-grinding.

2. The nose end of the blank is ground to clean, registering from the back and rough-ground side, Fig. 245.
3. The piece is reversed, and the back ground from the nose and rough-ground side, Fig. 246.
4. Again mounted on the inclinable magnetic chuck, set at the half angle of the punch, the remaining side is rough form-ground, Fig. 247. At this stage, the punch has .002" stock left all over.
5. Using normally corresponding diamond and stylus, the wheel is dressed to the finished form. The rough-ground punch is then finish form-ground in the same setup as used in step 4. The radii are measured optically in a projector and the overall dimensions are measured mechanically by means of a comparator.

6. The tail is ground to dimensions from the nose, Fig. 248, thus completing the punch.

The die sections are form-ground from hardened blanks, Fig. 249, as follows:

1. Grind one side to the correct angle on the inclinable magnetic chuck, Fig. 250.
2. The back is ground in proper angular relation to this side, Fig. 251.
3. The nose end is ground from the back, leaving exactly .002" stock, Fig. 252.
4. Using the same setup as in step 1, the second side is ground, leaving .002" as measured at nose. This is checked as shown in Fig. 253.
5. The form, with the exception of the step, is rough-ground within .002" of size in both sides on the inclinable magnetic chuck set to the included angle of the part, Fig. 254. This can be checked to a projected layout.
6. The step is rough-ground in the same setup, Fig. 255, leaving the same stock allowance. The angles of the side are finish-ground in the same setup as used in step 1, working to a pin

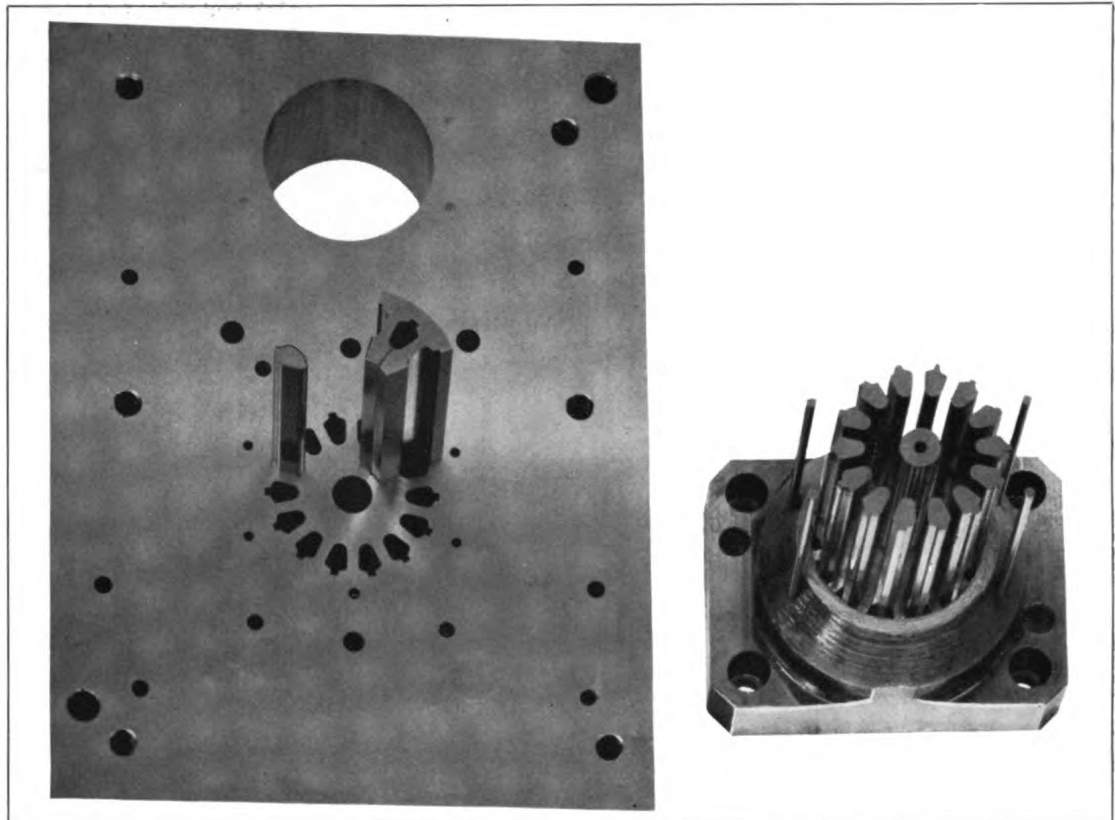


Fig. 242 — The rotor-piercing station poses a problem of linear form grinding.



Fig. 243 — Interchangeable punches and die sections of the rotor-piercing station.

dimension checked in the fixture, Fig. 253, with an electronic comparator.

8. The step is finish-ground as in operation 6, working to a pin dimension, Fig. 256.
9. Finish-grind the form, as in operation 5, working to pin dimensions from the nose. Final inspection is made to measurement over and between pins, Fig. 256, after radii have been optically measured.
10. The necessary draft is ground to within approximately  $\frac{1}{16}$ " of the end on the inclinable chuck, packing the end of the piece up from the chuck and away from the set-edge to give the required taper. In practice, one half of the form is first draft-ground on each side of one section, Fig. 257, the remaining half is then ground to a blend with the first. Draft is ground in the step last.
11. The radius, conforming to that of the Jig Ground hole which it must fit, is ground on the back from a template and formed wheel, Fig. 258.

## LINEAR FORM GRINDING PRACTICES

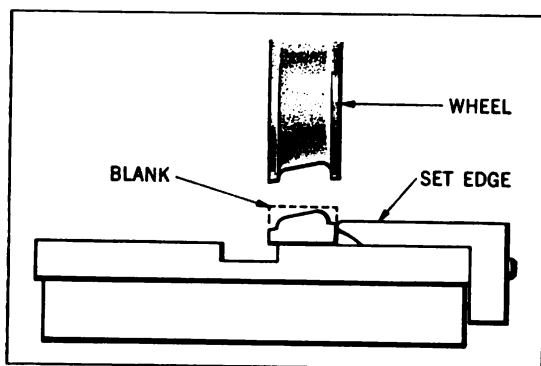


Fig. 244 — Punch blank rough form-ground, one side.

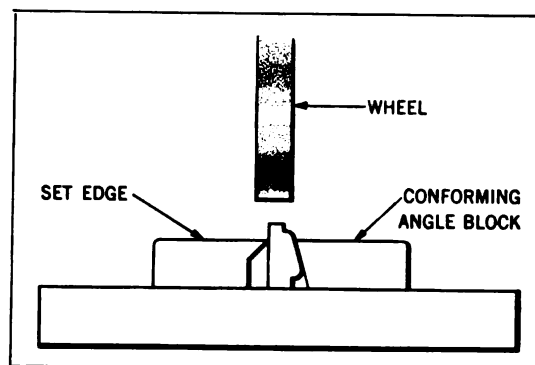


Fig. 245 — Grinding nose of blank to clean.

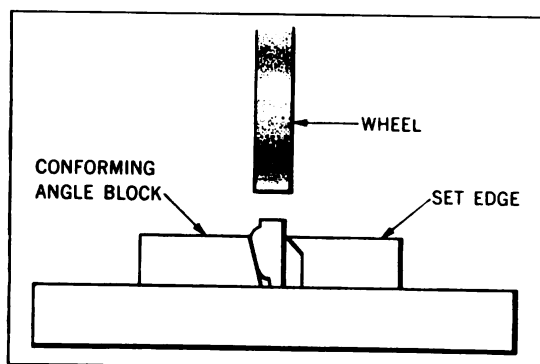


Fig. 246 — Grinding back of blank.

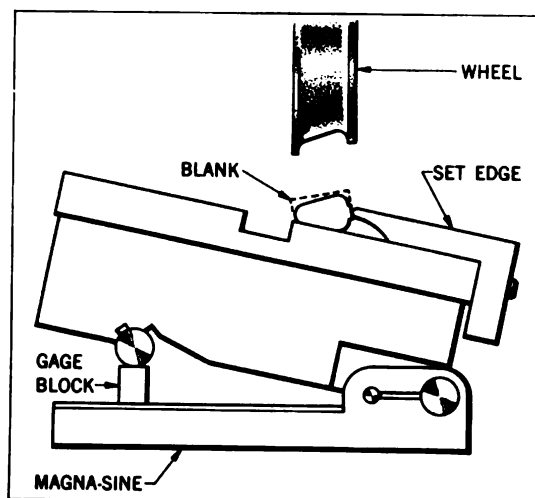


Fig. 247 — Rough form-grinding second side of punch.

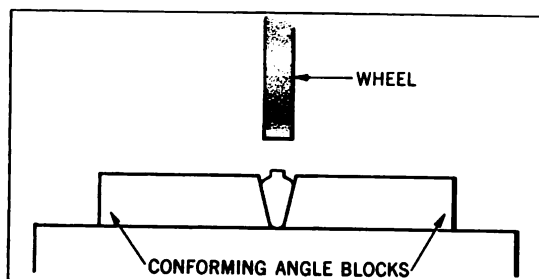


Fig. 248 — Tail is ground to finish dimensions from nose.

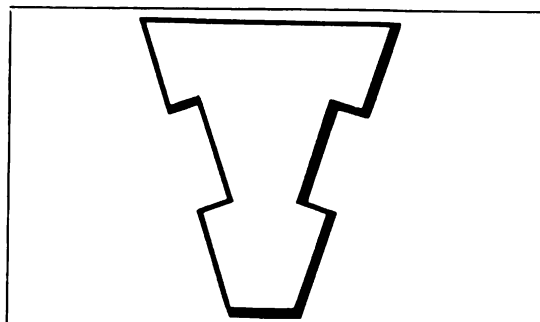


Fig. 249 — Die insert blank.

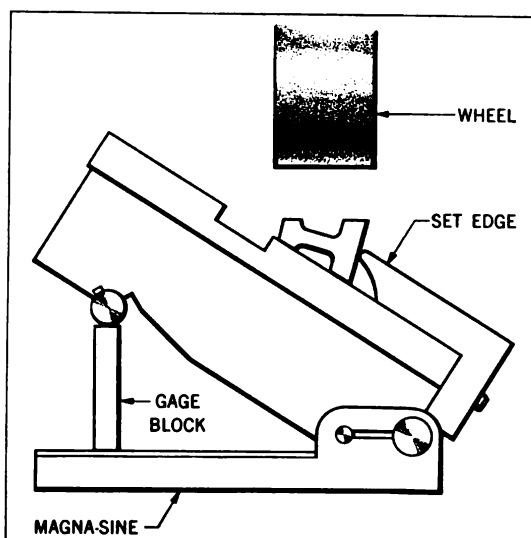


Fig. 250 — Grinding insert blank to correct side angle.

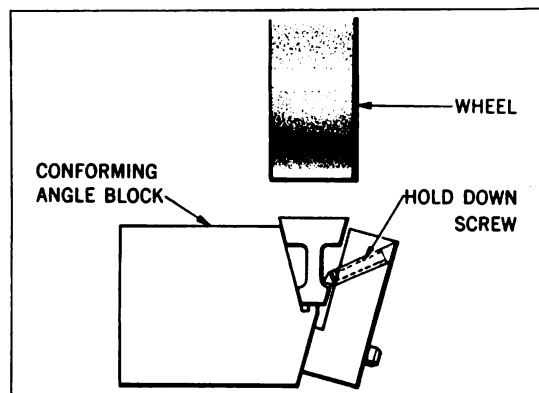


Fig. 251 — Grinding back in angular relation to side.

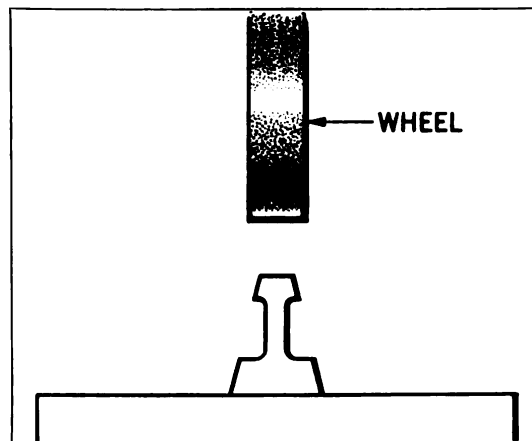


Fig. 252 — Nose is ground from back.

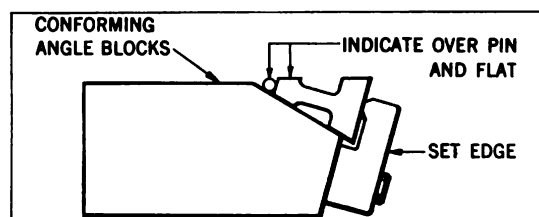


Fig. 253 — In checking result of preceding steps in a fixture, only one pin at nose is used.

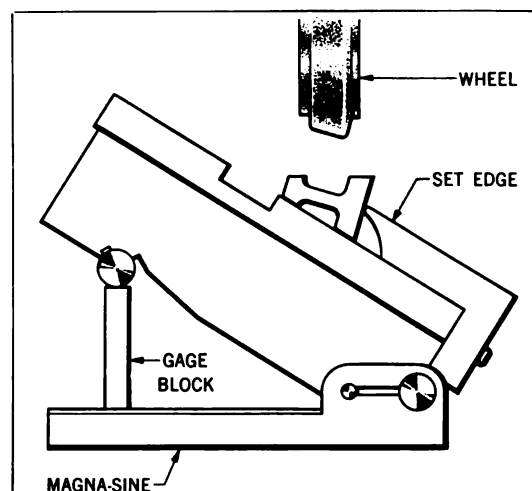


Fig. 254 — Rough-grinding the form on the insert.

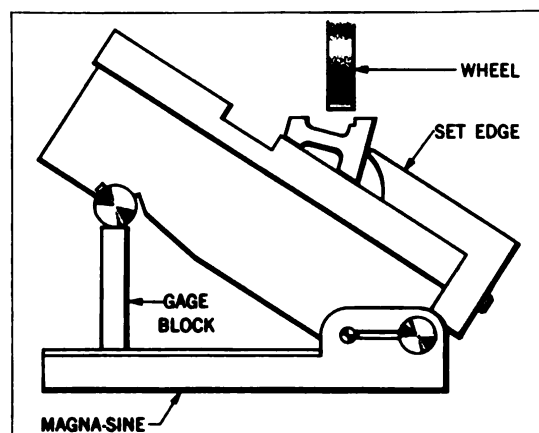


Fig. 255 — Rough-grinding the step.

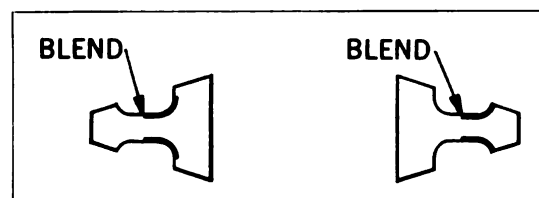


Fig. 257 — Draft is ground on half of form on all punches and blended to other half which is ground in a second operation.

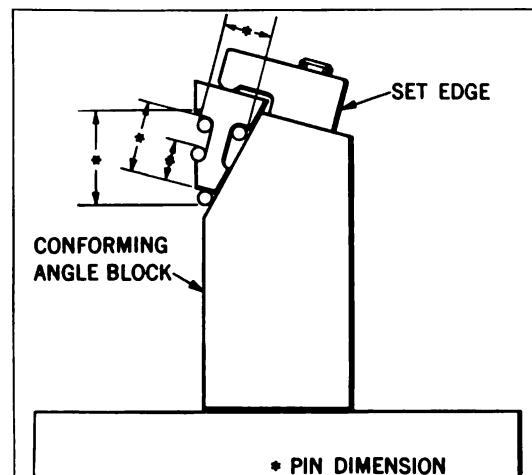


Fig. 256 — Relation of step to nose and roughed form is checked with pins and indicator.

## LINEAR FORM GRINDING PRACTICES

The preceding example involves most of the accepted linear form-grinding practices. Variation of these operations, a knowledge of the principles involved, and a degree of ingenuity in evolving special techniques when necessary, should provide for grinding any linear form likely to be encountered.

**Form-Grinding Carbide** — Carbide die life is largely a function of the accuracy of the component parts. Too much stress, therefore, cannot be put on the importance of accurately grinding these parts, Fig. 259. Many premature tool failures can be traced directly to inaccuracy in the difficult task of linear form-grinding this material. Fortunately the design of both the Panto-Crush Wheel Dresser and the Form Grinder lends itself directly to the accurate and efficient performance of this operation.

The universally familiar safety razor blade, Fig. 260, produced by the Boston plant of the

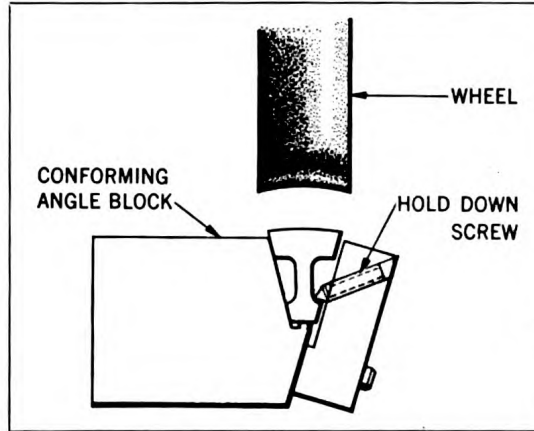


Fig. 258 — Grinding the radius on the back, which must conform to hole that will receive it.

Gillette Safety Razor Company, provides an outstanding example of linear form grinding of carbide press tools in production quantities. Production of over two billion blades per year in this one plant alone emphasizes the eco-

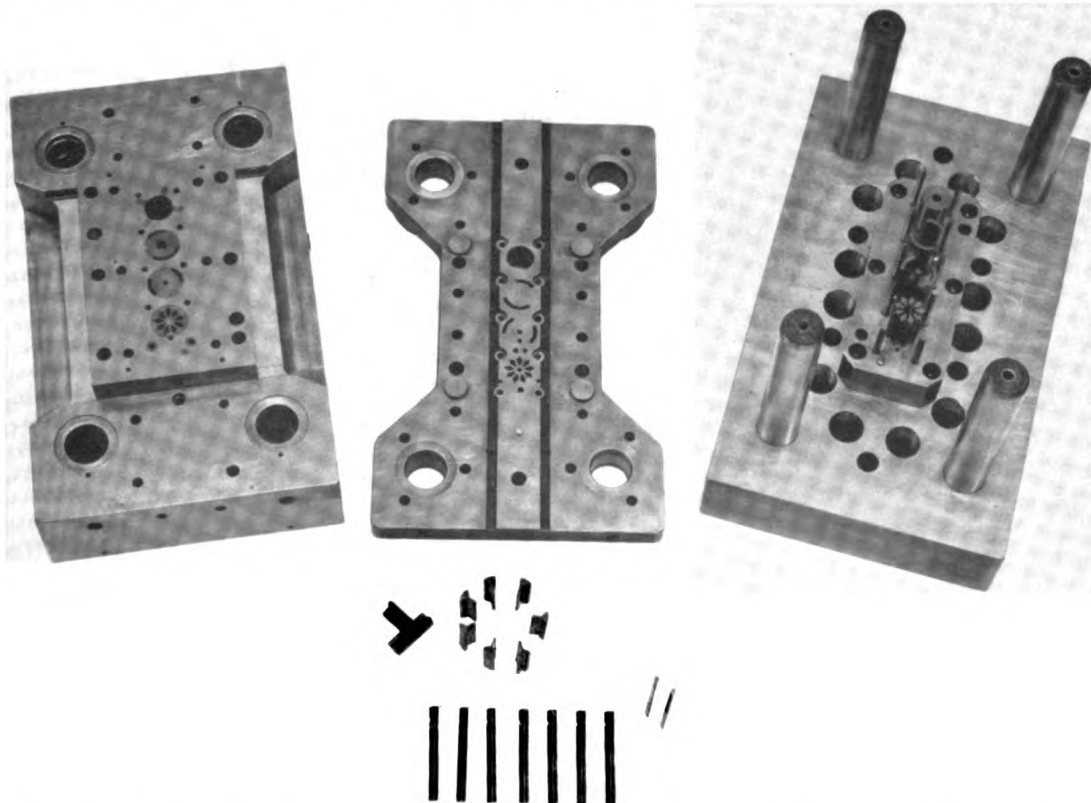
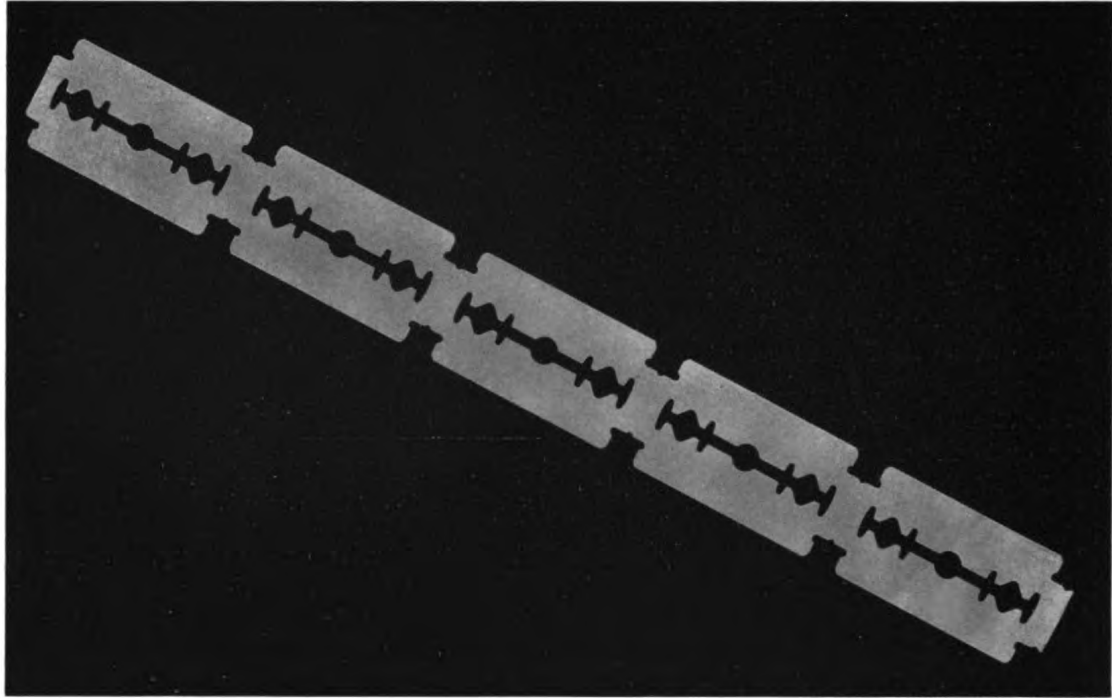


Fig. 259 — This carbide die is typical of the interchangeability attainable by grinding contours to dimensions. The extra punches and inserts are provided as an added service to the customer in case of accidental breakage in service.



Courtesy of Gillette Safety Razor Co.

Fig. 260 — Very close tolerances are required to permit the use of interchangeable press tooling with material of this extreme thinness.

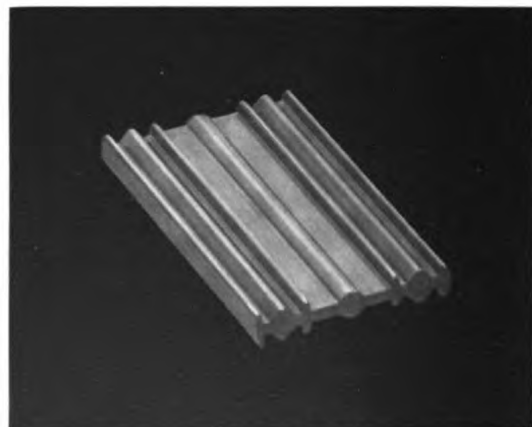
nomic importance of the required press tools.

Average life of a tool-steel die was 100,000 blades per grind, requiring replacement of one complete tool every week of production. The progressive attitude of the Gillette Company is reflected in their changeover to carbide dies for this operation, with a resulting increase of 30 to 1 in the number of blades produced per grind and during the total life of the tool.

This ratio would mean little were it not for the fact that these carbide die parts are form-ground on the Moore Panto-Crush Wheel Dresser to a clearance of .0002" between the punch, Fig. 261, and the die sections, Fig. 262. The cost is only three times greater than a duplicate steel part. Made in production quantities themselves, these tools must be completely interchangeable to an even greater degree than the blades which they produce.

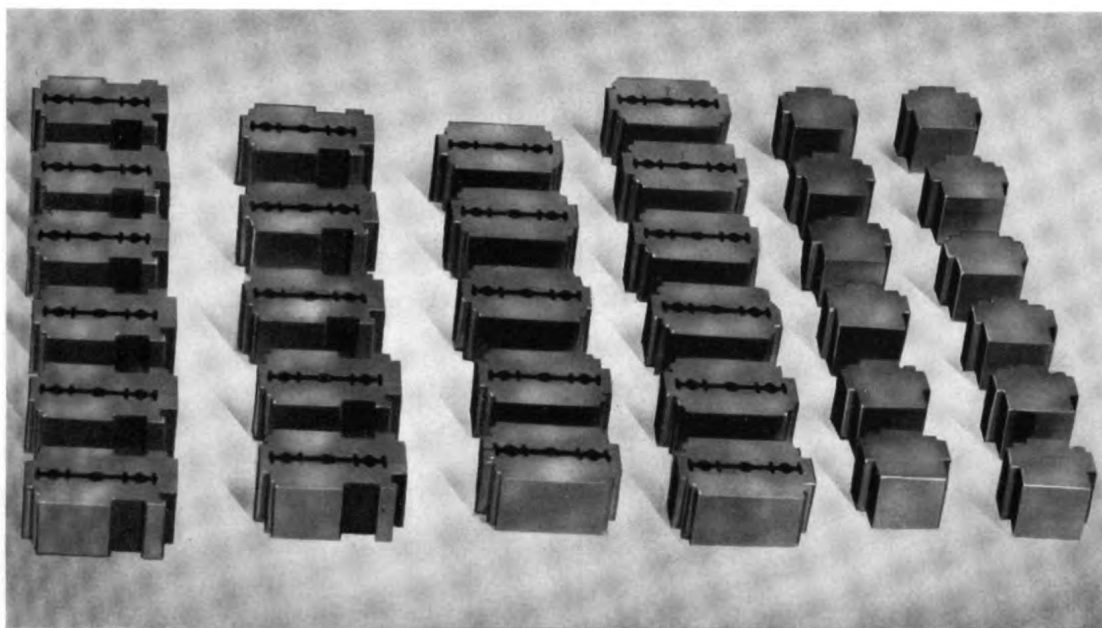
The obvious saving in the use of a material which extends the life of the tool by a ratio of 30 to 1, at a cost increase of only 3 to 1, decreases the tool cost per blade to one-tenth

that of tool-steel dies! This savings ratio extends also to the maintenance and operation of the carbide press tools. It is reflected in a reduction of tool maintenance man-hours, in less frequent interruption of production for adjustment, grinding and replacement of dies, with the attendant enforced idleness of press and operator.



Courtesy of Gillette Safety Razor Co.

Fig. 261 — This solid carbide punch is linear form-ground from the solid by the matched form method.



Courtesy of Gillette Safety Razor Co.

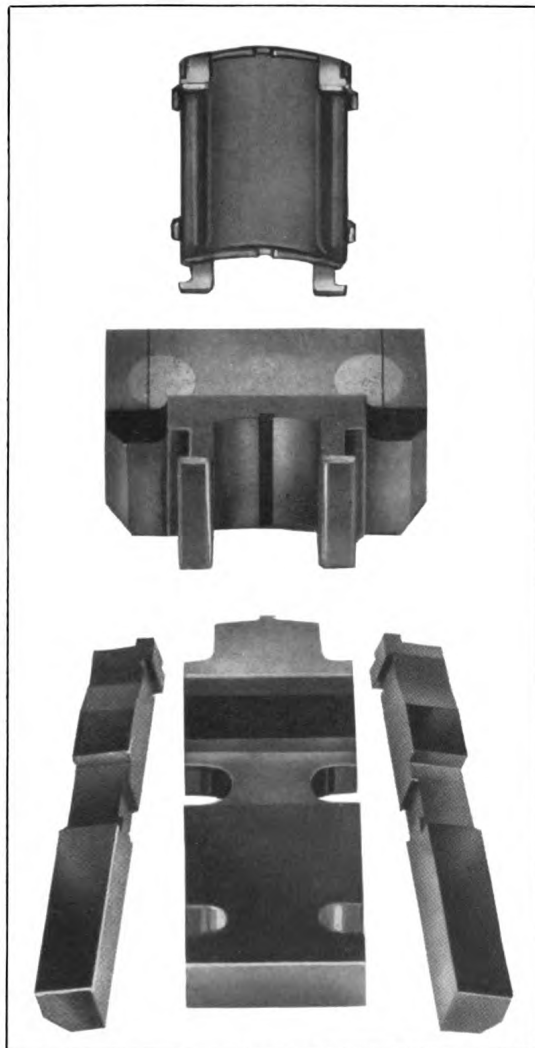
*Fig. 262 — Made in lots, the solid carbide die sections represent interchangeable tooling handled as a production job.*

Equally substantial savings in Gillette tool costs result from form-grinding the carbide die parts, Fig. 263, for trimming the hooks on part of the razor frame, and the carbide press tools, Fig. 264, for piercing the lather slots in another razor part.

The only effective abrasive for form-grinding carbide is diamond powder. Conventionally, this is impregnated to some depth, usually  $\frac{1}{8}$ ", in the rim of a plastic or metal wheel. Such a wheel is virtually impossible to form to a desired contour with any accuracy; even were it possible, a large proportion of the expensive diamond would be wasted. Simple forms such as angles and radii are available, however. Their use will be explained later.

**Diamond-Charged Wheels** — High accuracy and efficiency, together with economy in time and material, can be realized by use of the formed, diamond-charged wheel, Fig. 265, actually made on the same machine which utilizes it in form-grinding carbide. This type of wheel derives its accuracy of form from the same template-pantograph principle, described in the preceding chapter, in the following sequence:

1. A conventional abrasive wheel is dressed to the required form from a template.
2. The integral crusher roll of the Panto-Crush, Fig. 224, or the self-powered, chuck-mounted crusher roll of the Form Grinding Machine, Fig. 266, is cylindrically form-ground from the wheel.
3. The abrasive wheel is removed from the spindle and replaced with a copper-rimmed aluminum wheel, Fig. 267, available as an accessory.
4. The dressing diamond is replaced with a special carbide tool of exactly the same size, shape and accuracy, and the form is turned in the copper rim from the template. This operation is performed in the same manner as wheel dressing. By advancing the tool as explained in method 1, page 179, the form is reduced slightly in size to allow the projection of the diamond abrasive to be used. For roughing grit, .001" should be allowed; for finishing grit, .0005". The form thus produced will exactly fit that of the previously ground crusher roll with the projecting abrasive between, Fig. 268.
5. The crusher roll is misted with light oil and its form uniformly sprinkled with diamond powder. For roughing, a 60 - 100 grit powder should be used and 180 - 220 grit for finishing. With the wheel spindle stopped, the rotating crusher roll and wheel are brought into mating contact.



Courtesy of Gillette Safety Razor Co.

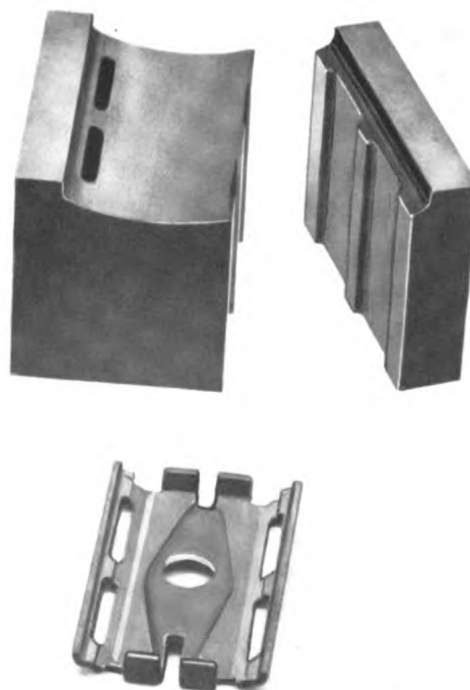
Fig. 263 — The life of necessarily delicate carbide sections such as these is largely dependent on their accuracy.

The forcing together of the mating forms of the two members firmly embeds the diamond particles in the copper rim.

As an alternative to the crusher roll, a crusher bar may be used as follows:

1. A hardened bar of adequate cross section is mounted on the magnetic chuck and form-ground in exactly the same manner as a work-piece, Fig. 266. This bar should be approximately equal to one-third the wheel diameter in length.
2. The abrasive wheel is removed from the spindle and replaced with a copper-rimmed aluminum wheel, Fig. 267, available as an accessory.

3. The dressing diamond is replaced with a special carbide tool of exactly the same size, shape and accuracy, and the form is turned in the copper rim from the template. This operation is performed in the same manner as wheel dressing. By advancing the tool as explained in method 1, page 179, the form is reduced slightly in size to allow the projection of the diamond abrasive to be used. For roughing grit, .001" should be allowed; for finishing grit, .0005". The form thus produced will exactly fit that of the previously ground crusher bar with the projecting abrasive between, Fig. 268.
4. The crusher bar is misted with light oil and its form uniformly sprinkled with diamond powder. For roughing, a 60 - 100 grit powder should be used and 180 - 220 grit for finishing. With the wheel spindle stopped, and the table reciprocating, the wheel is lowered to bring its form into that of the bar. Increasing downfeed pressure causes the moving bar to rotate the wheel and forces the diamond particles into the formed copper rim, where it is firmly anchored. Since the bar is shorter than the wheel circumference, only a portion of the wheel can be



Courtesy of Gillette Safety Razor Co.

Fig. 264 — Surface finish of form-ground carbide parts is an important aspect of the job.

## LINEAR FORM GRINDING PRACTICES

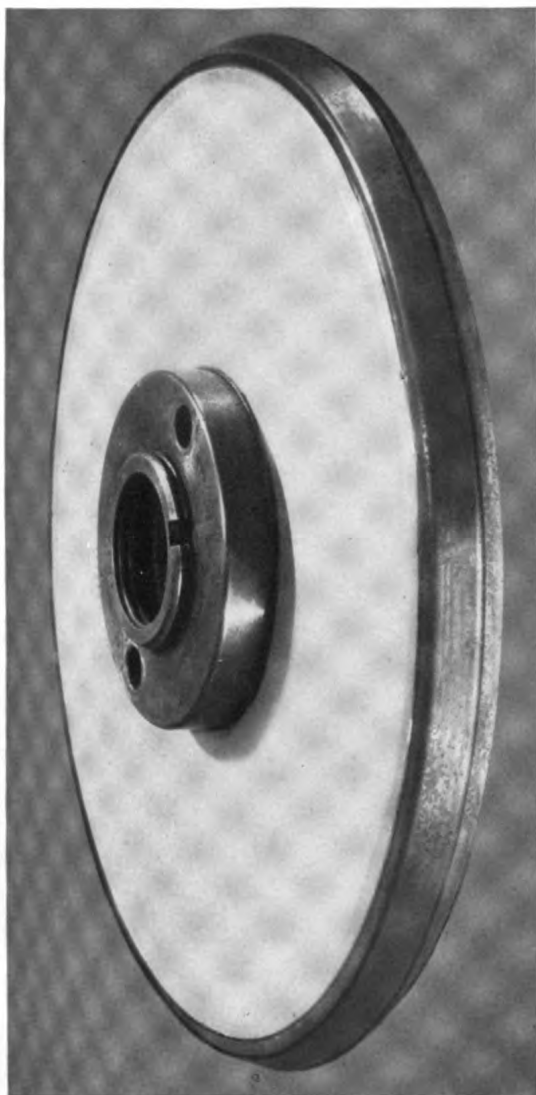


Fig. 265 — Form-turned, diamond form-charged, this wheel is highly efficient in carbide form grinding.

charged at a time. The wheel should not be allowed to run off the bar at any time during this operation. Indexing the wheel in relation to the bar permits charging its entire periphery.

The accurately formed wheel, charged by the methods described, can be made in the machine on which it is to be used in half an hour, at a fraction of the cost of impregnated wheel of lesser accuracy.

Extra copper rims are available, so that in changing forms, the old rim is cut through with a saw and a new one shrunk in place.

**Carbide Grinding Techniques** — There is considerable advantage in the use of commercially available preformed blanks for certain standardized parts customarily form-ground in carbide. The actual grinding practices are similar in most respects to those employed in grinding a comparable steel part, with the following variations:

1. Forms requiring considerable stock removal benefit from the use of standard radius or straight-faced, impregnated diamond wheels for pre-roughing. In this way the largest proportion of the stock is removed without wear on the formed wheel.
2. No more than a "tenth" or two downfeed per pass should be attempted. The natural tendency to crowd the feed will distort the form on the copper rim.
3. While the ideal coolant-lubricant is kerosene, it is so objectionable to the operator that conventional coolant is generally used, with satisfactory results.
4. Carbide cannot be held by magnetic attraction. The easiest solution to this problem is to use

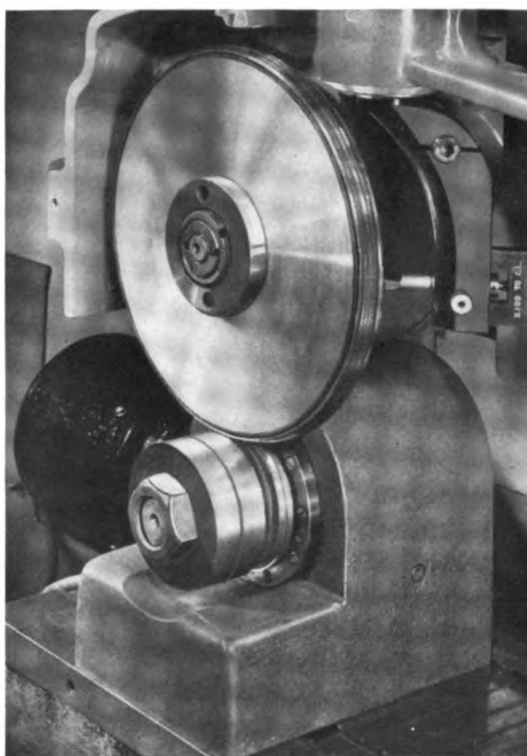


Fig. 266 — Form-ground crusher roll in place on chuck.



Fig. 267 — Copper-rimmed wheel mounted on spindle.

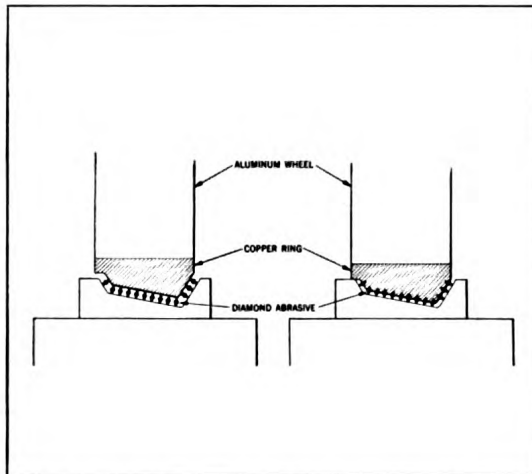


Fig. 268 — Diamond particles project from copper by amount allowed for them in relating the form on the crusher roll or bar to that turned on the rim of the wheel.

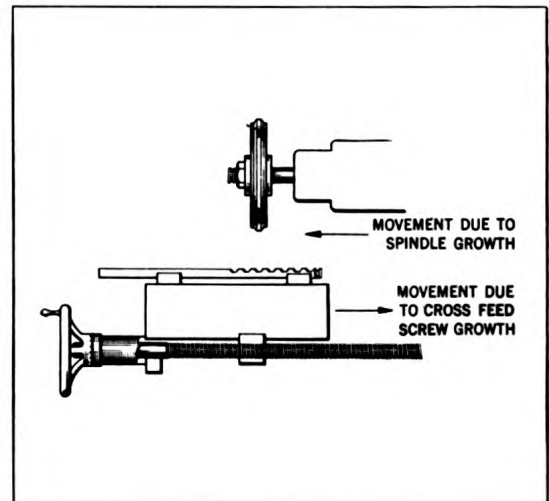


Fig. 269 — Effect of axial spindle growth or cross slide movement on form.

## LINEAR FORM GRINDING PRACTICES

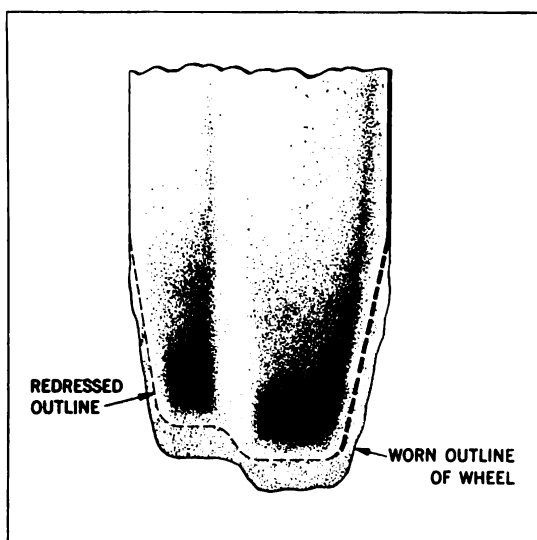


Fig. 270 — Re-dressing wheel to width is wasteful in the case of nearly parallel-sided forms.

magnetically held steel pieces to “back-up” the carbide and hold it in place. Where the shape of the piece does not permit this, tape with pressure-sensitive adhesive on both faces provides an alternative work-holding method. Still a third possibility exists in the use of a fixture, or nest, equipped with hold-down screws.

**General Practices** — To an even greater extent than in Jig Boring or Jig Grinding, linear form-grinding practices are subject to modifications imposed by the conditions of any specific job. The following notes on general practices are not, therefore, necessarily applicable in all cases.

1. A continuously energized electro-magnetic chuck develops heat which may result in dimensional errors in the work being ground. For this reason, the non-heating, permanent

magnet type of chuck is often used advantageously.

2. Diamond-charged, formed wheels grind most efficiently at 6,000 surface feet per minute and by coincidence are most efficiently turned at this speed.
3. Displacement of form in relation to the chuck set-edge can result from temperature-induced axial spindle growth or movement of an unclamped cross slide, Fig. 269.
4. It is frequently preferable to grind parallel or nearly parallel sides of a form in separate operations. This avoids the necessity of maintaining this dimension in the dressed width of the wheel. Re-dressing to width would entail the removal of a large amount of wheel material, Fig. 270.
5. Necessary blending of portions of a form, as is customary in grinding draft, is facilitated by blueing the finished surface and grinding the remaining surface with an overlapping width of wheel, until it just removes the blue at the blending line.
6. It is advisable to rough form-grind completely before attempting to finish-grind *any* portion of a piece. In this way, the effect of distortion from roughing is minimized.

While linear form-grinding practices discussed in this chapter represent the basic principles, they likewise provide a background from which suitable variations can be made to suit the requirements of any specific job. For example, the procedure outlined for the lamination die punches and inserts is intended to show *all* of the requisite steps for the attainment of highest accuracy; many of them can be consolidated when somewhat less than the highest accuracy is acceptable.



*Inspection Methods.*

## INSPECTION METHODS

THE PROBLEM of location involves not only *establishing* it, but also *verifying* it by inspection. The difference between dynamic values encountered in machining and static values involved in inspection, as stated in Chapter 1, might imply more of a differential in accuracy between these operations than actually obtains.

A close analogy can be drawn here. The comparison begins with "toolmaker" locating methods (Chapter 2), and their companion "surface plate" methods of inspection, Fig. 271. *Both were evolved from the necessity of accomplishing the job with whatever means were at hand.*

Essentially, the problems of location and inspection are comparable; they differ mainly in degree. Therefore, both benefit proportion-

ately from improvements in equipment and methods. The transition from makeshift *toolmaker* methods of location to the *engineered* solution (Chapter 4) makes it mandatory to upgrade similarly the methods of inspection. Failure to do so introduces an irreconcilable and continuing disagreement between the results of location and the findings of inspection. This is so because of these three basic factors:

1. The inspection of work under different conditions and by other means than were employed in establishing the location.
2. The necessary reorientation of the work, often from reference points other than those used in locating.
3. The dimensional errors inherent in this indirect and often lengthy technique.

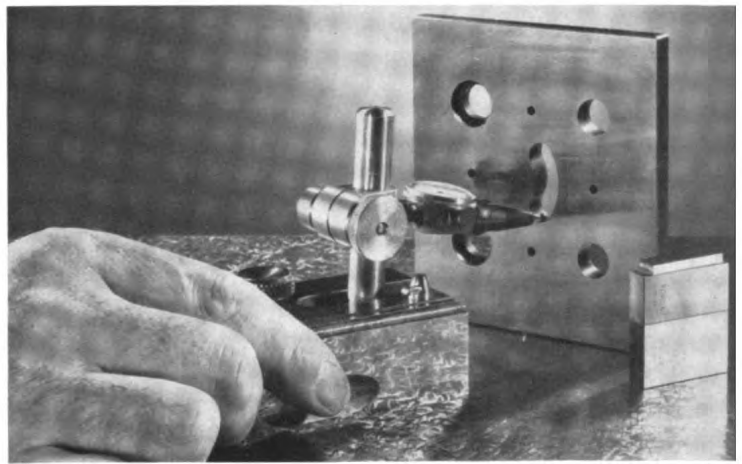
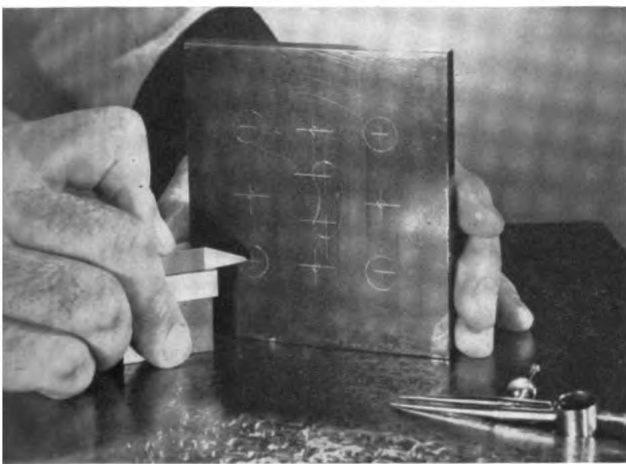


Fig. 271 — Surface plate inspection is closely related to toolmaker's locating methods.



Fig. 272 — Angular misalignment is not readily detected in vernier caliper measurement of hole location.

A survey of “surface plate” locational inspection methods will reveal the sources of error cited in point 3, above:

1. Vernier calipers, Fig. 272, provide a rapid but inaccurate means of measuring location. Inaccuracy is inherent in the relative crudeness of the instrument and the fact that it does not readily reveal angular displacement.
2. Standing the piece on edge on a surface plate and measuring the height of holes or surfaces from it. This involves the use of a height gage or indicator mounted on a surface gage and gage blocks for comparison. Whether the measurement be to the actual surface of a hole or to that of a tightly fitted plug, the result is dependent upon exact knowledge of diameter, half of which must be arithmetically added to the measured dimension in one case, or subtracted in the other, Fig. 273, in order to determine the location.

The use of a plug or pin introduces additional hazards which include:

- a) *The possible incorrectness of fit between it and the hole;*

- b) *any angular inclination of plug to hole results in an error magnified by the distance from the work-face at which measurement is made.*

In any case, after checking location in one direction, the piece must be turned 90°, so that rectangular distance may be measured. This step introduces the question of squareness between the two edges, both to each other and to the face of the work, Fig. 274.

The problem increases upon consideration of what is involved in the vastly more complex task of locational inspection of contours, Fig. 275. This introduces the measurement of male and female radii, chords or tangents to them, and surfaces in various angular relationships. In view of all of these considerations, it can no longer be a question of variation or further refinement of the “surface plate” method of inspection. Instead, a logical transition is indicated to specialized methods and equipment comparable to those which have proved so effective in solving the problem of establishing location!

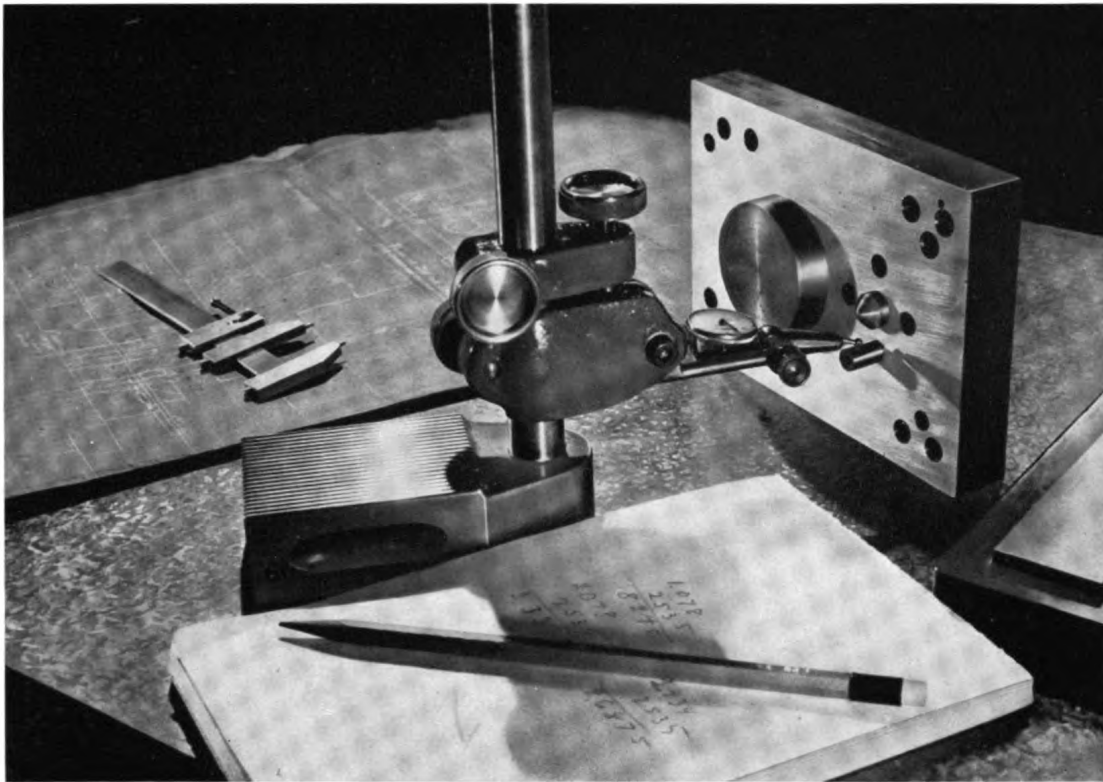


Fig. 273 — Measuring to a plug is an indirect means of establishing hole location.

Reflecting the close parallel between its kindred problem of location, inspection has also benefited from the adoption of interim solutions. These, in themselves, represent an improvement in efficiency and accuracy; more significantly, they point unerringly the trend to the ultimate engineered solution.

The toolmaker's microscope is representative of this transition, Fig. 276. Consisting of a fixed vertical microscope, beneath which is a small rectilinear compound and coordinate measuring system, it overcomes many of the disadvantages of "surface plate" inspection. It falls short of a complete answer for certain types of work for the following reasons:

1. It does not provide a convenient, rigid mounting for rotation of an indicator.
2. The work still must be reoriented to the datum of the coordinate system and to the directions of travel.
3. It is too small for inspection of a large proportion of average work, especially multi-station dies.

Fortunately, as the analogy between locating and inspecting has shown, the same solution is applicable to both. *In over 90 per cent of all cases, the Moore Jig Borer and Jig Grinder provide the most accurate and efficient means for inspecting their own work.* Only in the occasional

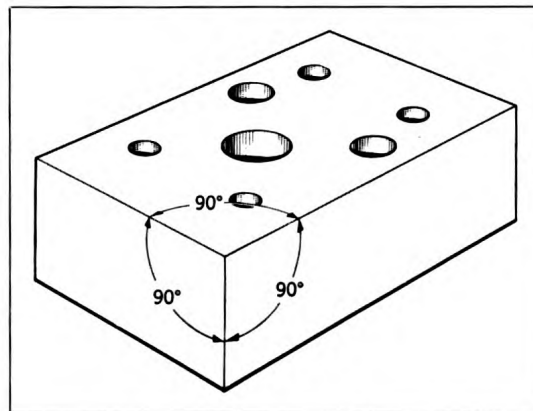
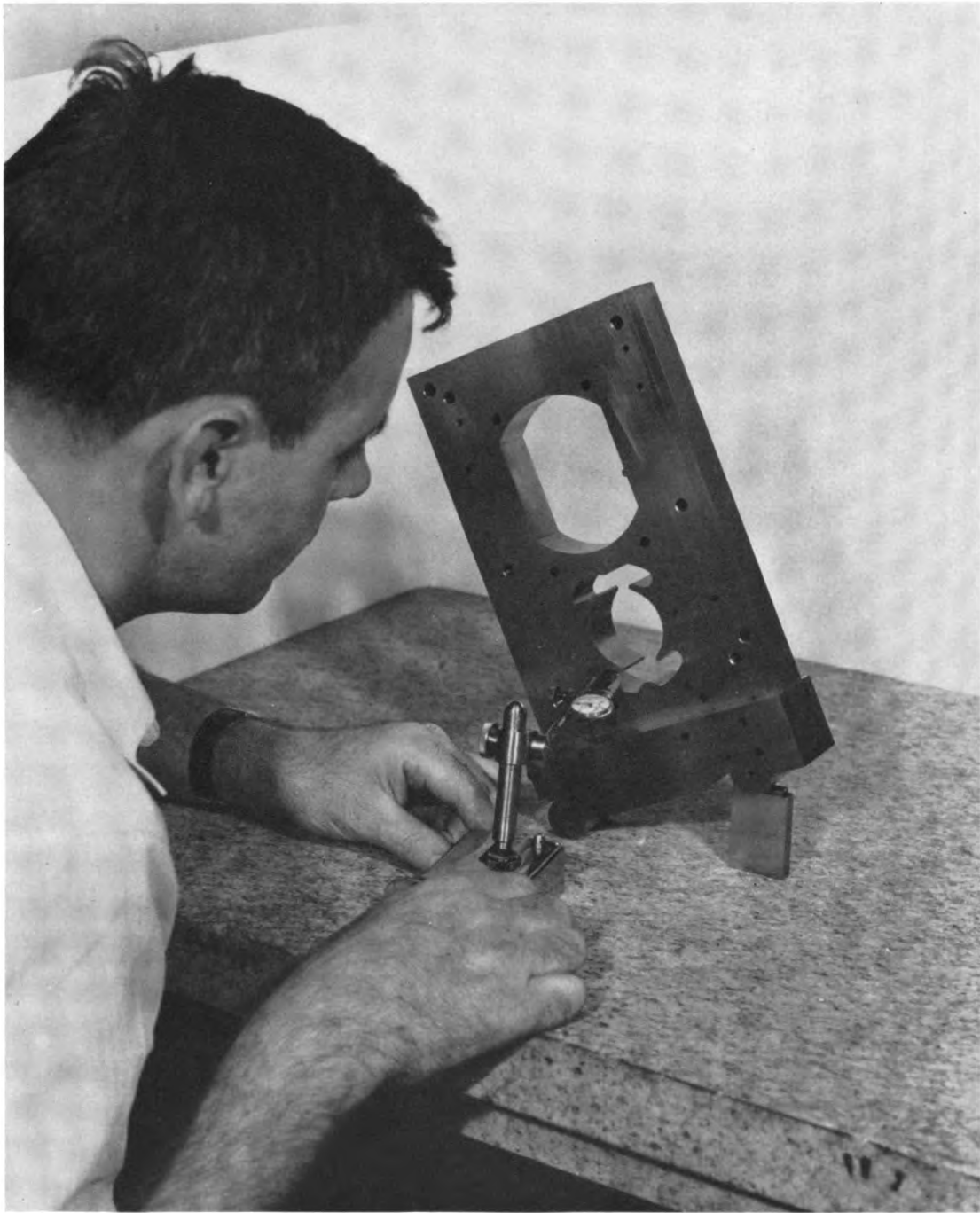


Fig. 274 — Surface plate inspection of hole location involves predetermination of squareness of edges to each other and to the face of the workpiece.



*Fig. 275 — As in establishing location, contours present a more serious problem of inspection than do holes.*

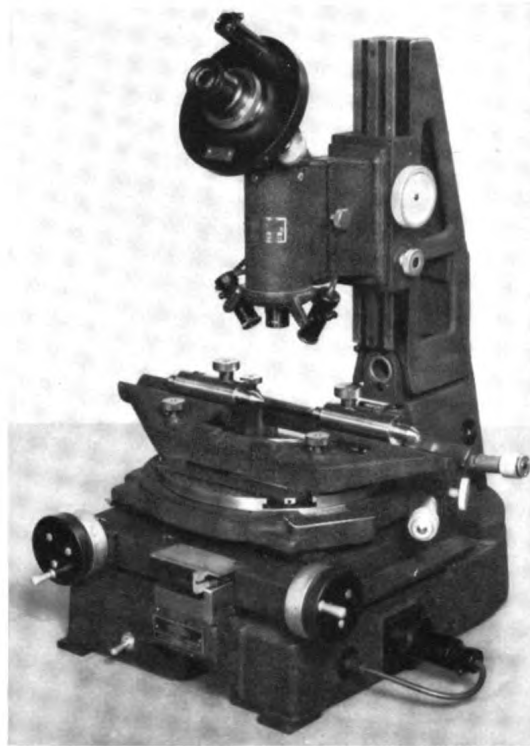
job, where inspection of location to an accuracy of a fraction of a "tenth" is critical, is it necessary to inspect Jig Bored or Jig Ground work in the Moore Measuring Machine. This will be discussed later in the chapter.

Advantages of using the Jig Borer or the Jig Grinder for inspection of their own work include:

1. Considerable saving of time results from checking the piece in the original setup, *while still*

*in the machine.* This not only saves time in inspection but — should an error be discovered — the work is in *position* for correction.

2. The same directness which reduced sources of locational error in comparison to toolmaker methods similarly reduces the number of steps and sources of error in inspection.
3. The machine's measuring system is fully as accurate as *any* standard which would be used in its stead. The inspection values, determined by means of this system, are likely to be *more* accurate than those attained by use of any other shop standard, because the transition or reorientation errors are eliminated.
4. The machine spindle provides a rotatable mounting for an indicator. Holes can be picked up directly in this manner, without the use of plugs or pins. Out-of-roundness, often mistaken for out-of-location, is easily detected and identified. Full 360° rotation of the spindle provides a double indicator reading of any error, thus increasing sensitivity. By vertical movement of the spindle and indicator the shape of the hole can be explored, revealing taper, bellmouth or barrel shape.
5. Contours, one of the most difficult, time-consuming jobs of inspection, can be rapidly and accurately measured and inspected by use of the "indicator measuring" technique, described in Chapter 10. Fig. 277 shows dimensions to be inspected on the same contour used as an example of contour Jig Grinding. Of this it might well be said, "How *else* would you inspect it?"
6. Work Jig Bored or Jig Ground to *polar* coordinates on the rotary table can be inspected to *rectangular* coordinates in the same setup. This not only provides a check on possible errors in settings; it eliminates sources of rotary table errors outlined in Chapter 5.
7. Paradoxically, the machines will actually inspect a bit more accurately than they will locate, under some conditions. This, again, is the advantage of static over dynamic values. During inspection, both the machine and the work are free of vibration, stresses and temperature differentials, so that the accuracy of the measuring system is undiminished. Minute errors from the latter source will generally be revealed as all in one direction. A re-pickup of the reference point will often serve to cancel them out.



Courtesy of The Gaertner Scientific Corp.

Fig. 276 — Toolmaker's microscope.

8. A microscope, interchangeable with the indicator in the machine spindle, Fig. 278, can pick up surfaces and small holes which cannot be conveniently reached with an indicator point.
9. Inspection of workpieces which would not stand unsupported on a surface plate can be made directly. This eliminates the introduction of angular error through use of setup members, such as angle irons or blocks, during inspection.
10. A wide variety of work which has *not* been produced on the Jig Borer and Jig Grinder can be effectively inspected by them. This includes measurement of pitch or lead of screw threads, Fig. 279, hobs and taps, as well as form tools, cams and gages.

In other words, the same combination of rectangular coordinate measuring system and perpendicular spindle which enables precise *location* of holes and contours provides the logical and effective inspection means for subsequently *verifying* them!

#### SETTING UP THE WORKPIECE

Assuming the work has just been Jig Bored or Jig Ground, and is still in position on the

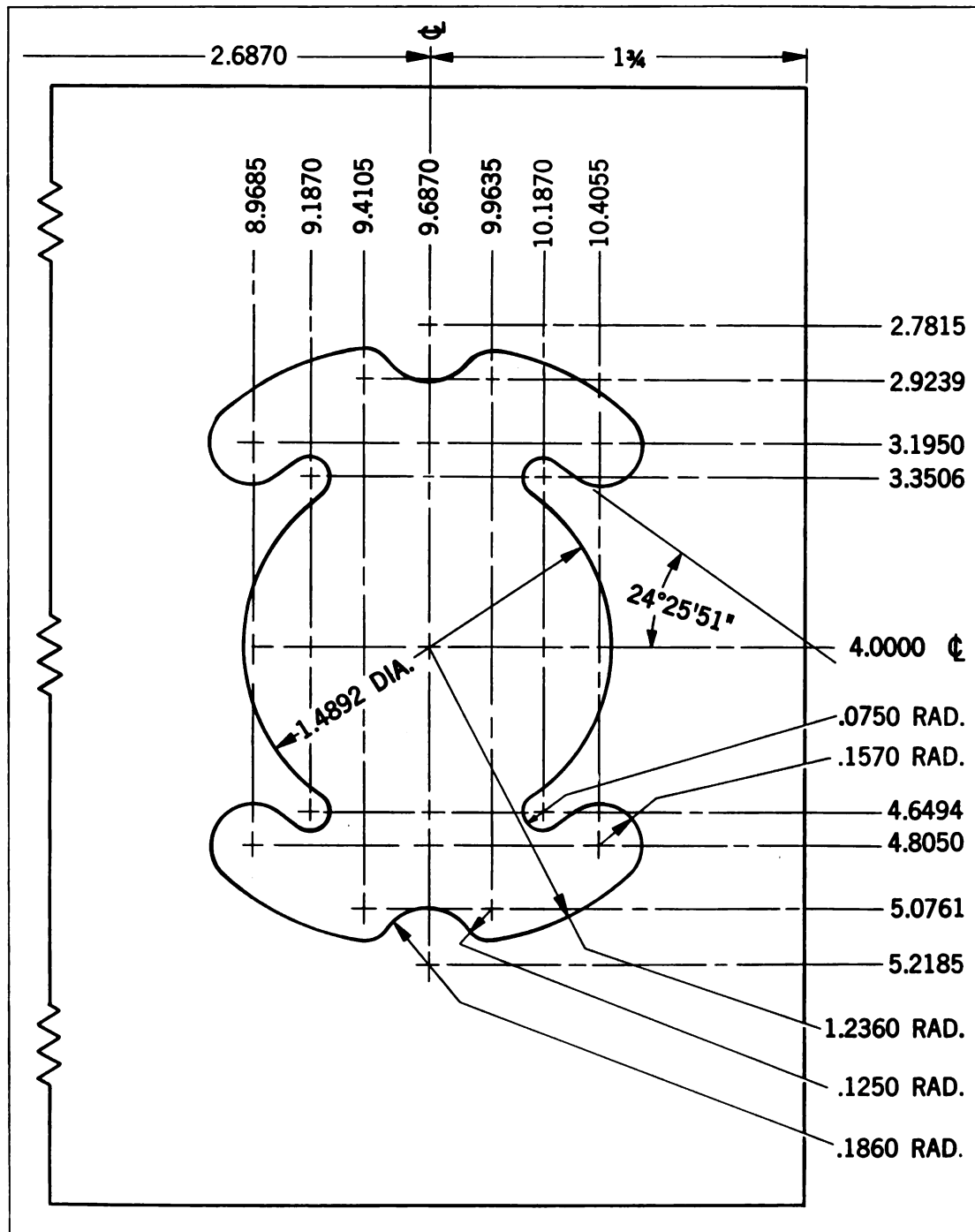


Fig. 277 — Without modern methods, a problem to inspect as well as to machine.

machine, setting up will obviously be unnecessary. However, should the setup have been disturbed, or should the piece to be inspected not have been Jig Bored or Jig

Ground, the points outlined under this heading in Chapters 7 and 9 can be applied to setting up for inspection. It should be mentioned here that, in view of the possible need

for reorientation in the process of averaging errors, the desirability of mounting certain types of work on a rotary table for the purpose is somewhat greater than when setting up for machining.

**Dimensional Pickup** — This vitally important step in inspection procedure should, under no circumstances, depend upon a pickup made for the machining operation. Since the objective of inspection is determination of locational accuracy of holes and/or surfaces, the *average* of their positions should be used in establishing the datum or reference of the work in relation to the spindle axis and coordinate measuring system of the machine.

Quite frequently the *relationship* of these functional points to each other is infinitely more important than their combined relationship to the original datum, such as an edge, which might have been an arbitrary reference for machining. In such cases, the latter can be considered as secondary and, if necessary, later to be corrected.

Reorientation, or averaging of location, during dimensional pickup preparatory to inspection, may be of the following nature:

1. Linear, or in one direction of the machine travel, Fig. 280.
2. Rectilinear, or in both directions of machine travel, Fig. 281.
3. Angular to a direction of machine travel, Fig. 282, or any combination of these necessary to effect a compromise pickup which will bring the location of *all* functional points within the limits of their respective locational tolerances.

After pickup, the scales and dials are re-set, as described in Chapter 5. In this respect, dimensional pickup is similar to the procedure of "mapping the campaign" preparatory to Jig Grinding. The basic difference is that, in one case, the danger lies in failure to "clean up"; in the other, it presents the possibility of one or more points falling outside the limiting locational tolerance.

**Inspecting Holes** — Determination of the true location of the axis of a hole by inspection on a Jig Borer or Jig Grinder does not presuppose a knowledge of its diameter. It does, however,

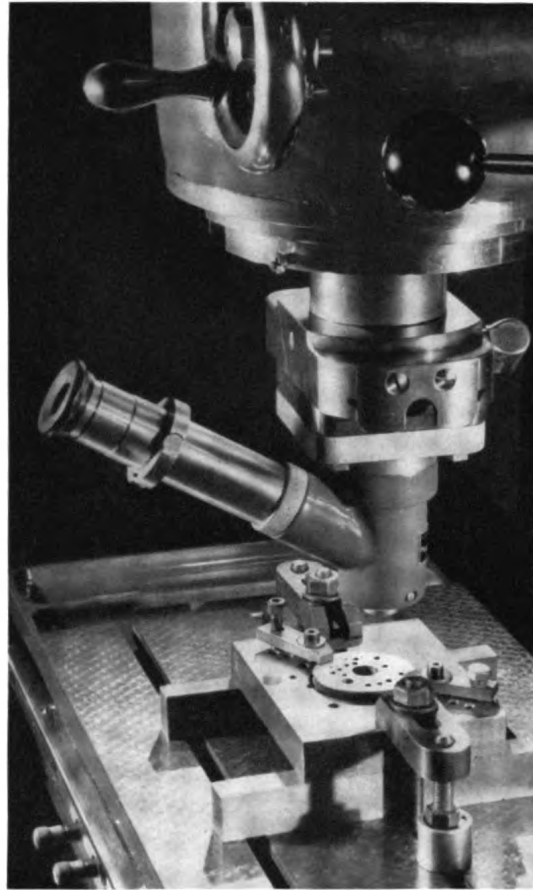


Fig. 278 — The microscope is a convenient aid in the use of a Jig Borer or Jig Grinder for inspection.

require exploration of its geometry — roundness, angle of axis to work surface, taper, bell-mouth or other departure from cylindricity. Fortunately, these can be revealed rapidly and accurately as a simple phase of inspection procedure.

Generally the most convenient inspection tool is the specially designed, horizontal face indicator, Fig. 283. This instrument has the distinct advantage of eliminating the need for a mirror or "neck craning" in attempting to read the dial of a vertical face model at a point  $180^\circ$  from an operator's normal position. Either of these expedients may introduce errors due to the reversal of mirror image and to parallax resulting from the spacing between needle and dial graduations, when viewed from an angle, Fig. 284.

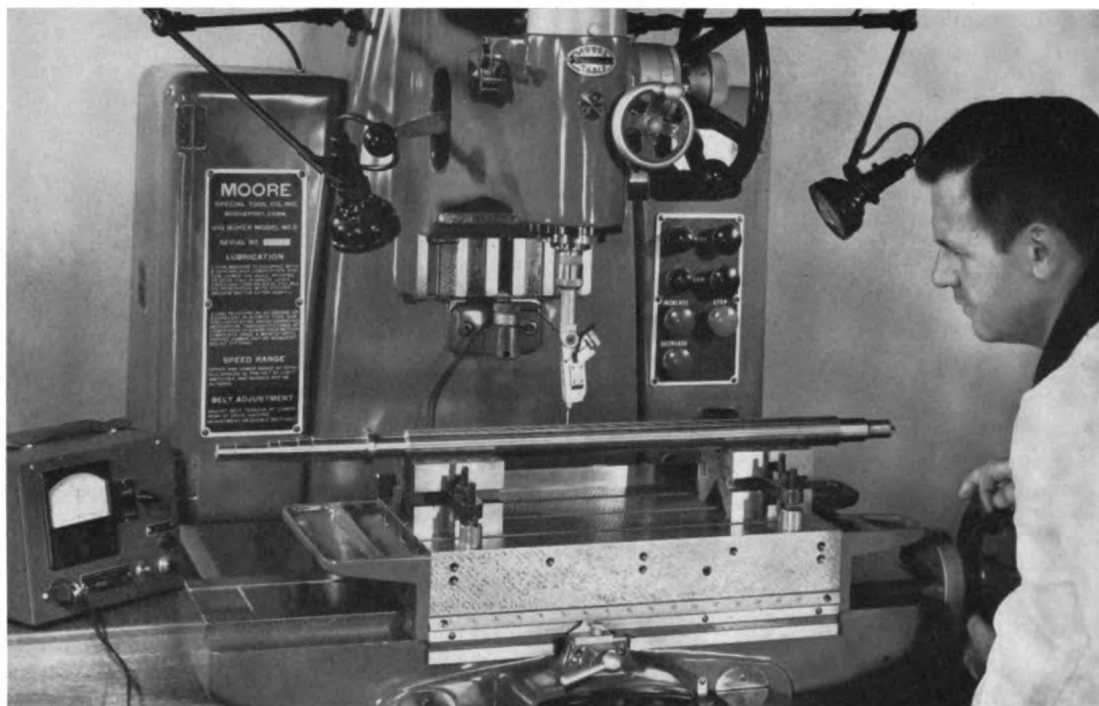


Fig. 279 — Measuring pitch, or lead, of a screw in V-blocks on a No. 2 Moore Jig Borer.

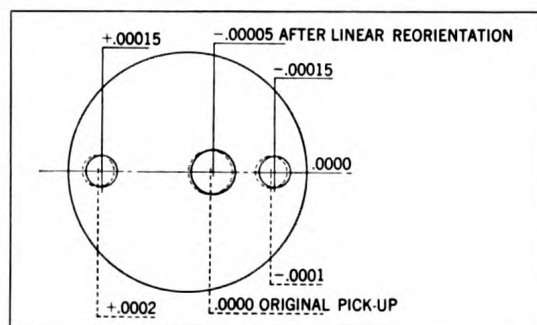


Fig. 280 — Linear orientation frequently succeeds in bringing locations within tolerance by averaging errors.

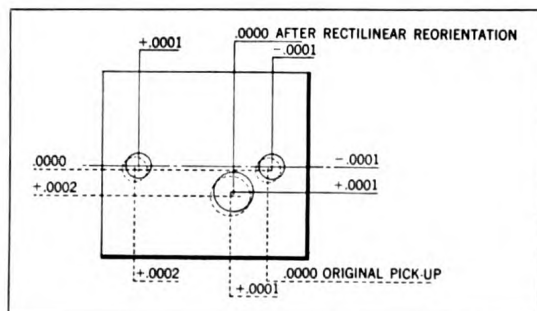


Fig. 281 — Rectilinear reorientation to average two directions of linear displacements.

These indicators are available with either .0001" or .001" graduations, and the latter is more practical. The former is so limited in range that it requires the workpiece to be within a very few thousandths of location before it can even be used. Also, its high magnification necessitates such high contact pressure for operation that an extremely rigid

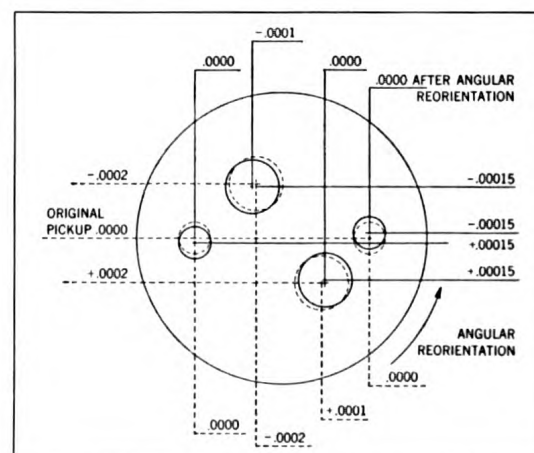


Fig. 282 — Angular reorientation is particularly effective in the case of a circle of holes.

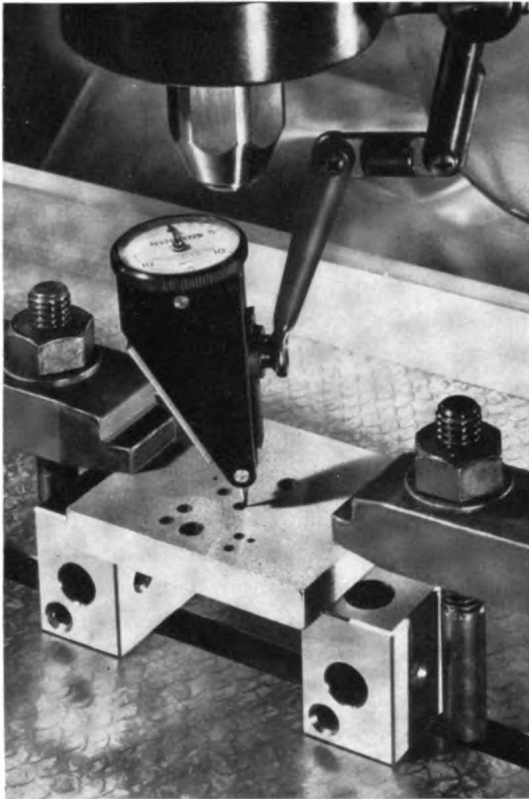


Fig. 283 — Horizontal dial indicator minimizes danger of false reading when used through 360°.

mounting must be provided, whereas ease of positioning is desirable in such a mounting.

By contrast, the .001" indicator permits reading as little as .0001" needle movement, provides an adequate range, and exerts very little contact pressure. It has much to recommend it in inspection, as well as in Jig Boring and Jig Grinding.

Roundness of a hole may be verified by positioning the work by means of rectilinear machine movement, so that an indicator contacting its surface does not change during a full revolution of the spindle to which it is attached. At this point, the spindle and the hole are coaxial, and the location of the latter can now be identified in relation to the measuring system of the machine.

Out-of-roundness is manifest by inability to position the work, so that no change in indicator reading is observed during a full revolution of the spindle. Failure to recognize

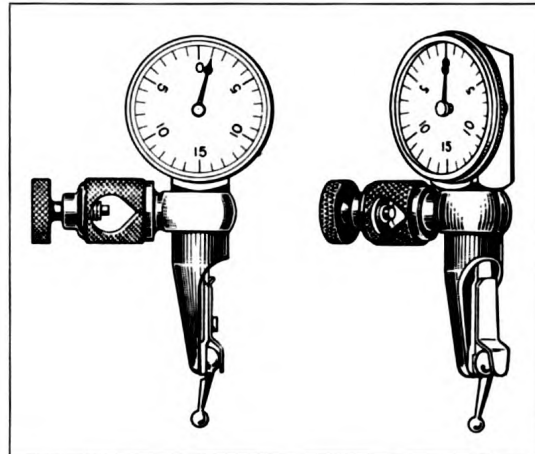


Fig. 284 — The necessary clearance between indicator dial needle and dial graduations introduces a parallax error when read at an angle.

this condition may lead to identifying it as out-of-location. The most common form of out-of-roundness is ellipsoidal, revealed by high indicator readings 180° apart, and by low indicator readings, also 180° apart but at 90° to the high, Fig. 285. In this case, the axis of the hole is determined by positioning the work, so that a full revolution of spindle and indicator produces a pair of equal high

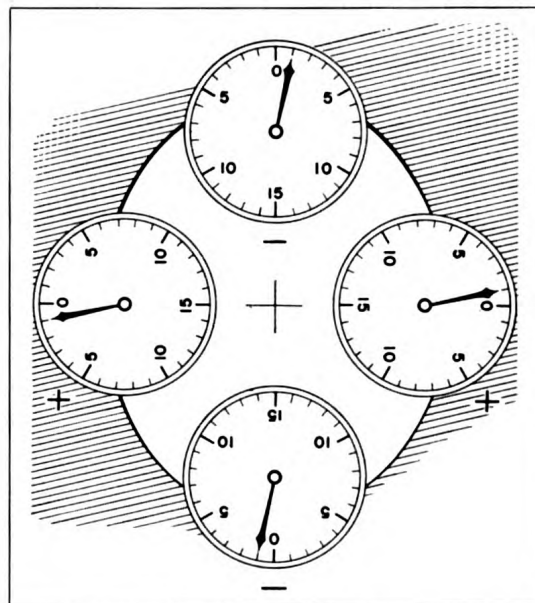


Fig. 285 — Typical indicator readings revealing an elliptical hole.

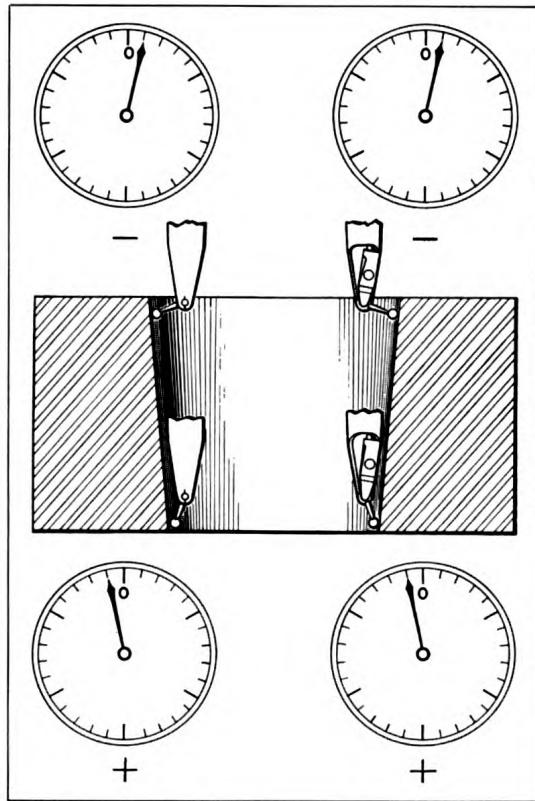


Fig. 286 — Taper in a hole is revealed by indicator reading during axial movement.

readings and a pair of equal low readings. Other non-symmetrically shaped holes require some judgment in “juggling” positions to determine the *true* position of what, at best, will be an *average* axis!

Taper can be detected by vertical movement of the indicator point through the length of the hole, contacting first one side, then the side opposite. In this case, the readings will progressively increase or decrease equally on both sides, depending on the direction of the taper, Fig. 286.

Angular inclination, or “lean” of the hole to the supporting face of the work, Fig. 287, is revealed by reversal of the reading down one side as compared with that of the side opposite.

Bellmouth and other deviations from true cylindricity are shown by *non-uniform* change in indicator reading during vertical movement, Fig. 288.

Only extremely small holes present a problem in this inspection use of the machines. This is due to the size of the indicator point, which may preclude traversing it the length of the hole. Close-fitting pins may be used to detect taper or bellmouth and, when projected above the face of the work, provide a surface which can be indicated as a means of detecting “lean,” Fig. 289.

**Inspecting Contours** — The location and controlling dimensions of contours are determined, during inspection on the machine, by the indicator measuring methods outlined in Chapter 10. However, some of the related techniques, such as the use of layout blue in establishing the blend of radii to each other and to tangent surfaces, are not applicable to inspection. Furthermore, it is desirable to inspect such points as the sharpness of corners and uniformity of draft. Therefore, the subject will now be approached as to its application specifically to inspection.

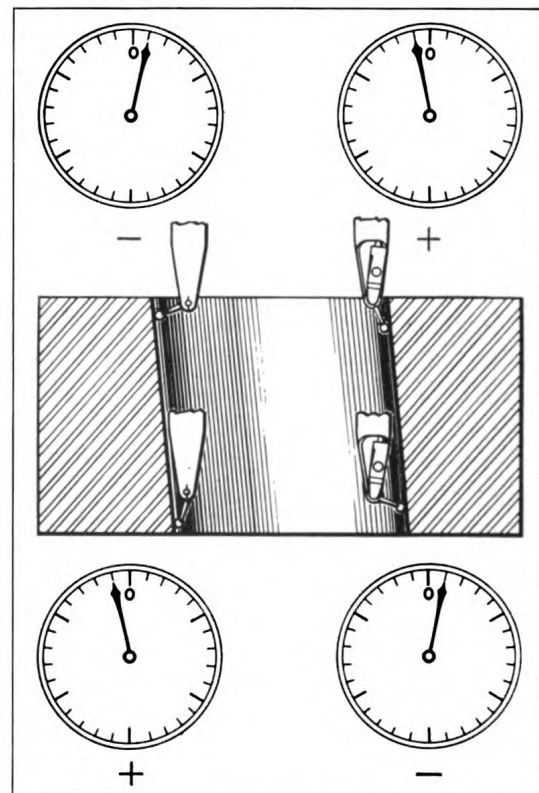


Fig. 287 — Lean of a hole shows up on the indicator.

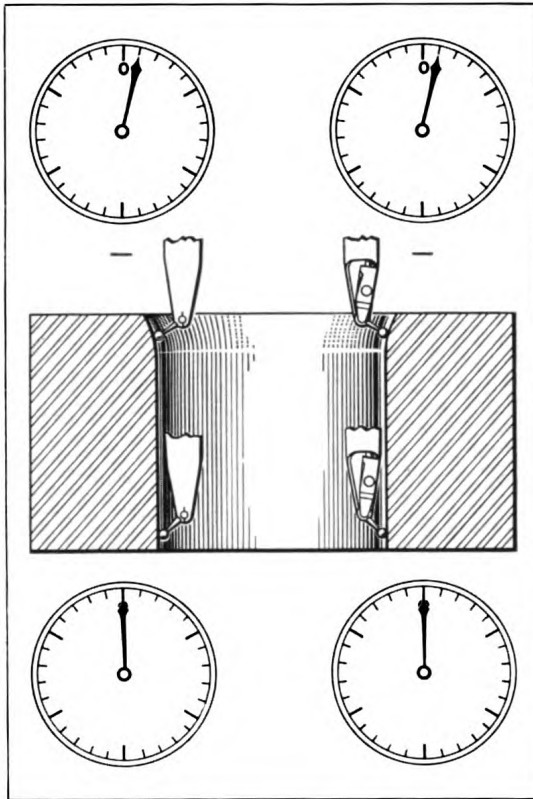


Fig. 288 — By disclosing bellmouth, the indicator completes its investigation of the geometry of a hole.

It should be emphasized that, preparatory to any inspection of contours by "indicator measuring," not only must a new pickup be made of the controlling locations of the *contour*, but also of whatever *edge* is used as a reference or datum for the machine measuring system.

It is generally desirable to use portions of a contour which are farthest apart as pickup points, in establishing a reference for inspection. For example, the axes of the four corner radii in Fig. 290 would be the logical choice for pickup. This is also in keeping with the fact that female radii, which permit full rotation of an indicator, are more easily and accurately picked up than male radii, which limit indicator rotation. The location of the axes of all radii, male and female, should now be verified by picking them up as done in the case of a hole or a pin.

Having completed this first step, it is neces-

sary to resort to indicator measuring, in order to determine whether the radii are, themselves, within their specified *size* tolerance. This is done by zeroing the indicator against the established reference edge which has been displaced from the spindle axis by an amount equal to the nominal dimension in question (see Chapter 10). With the axis of the radius to be measured re-positioned to align with that of the machine spindle, the indicator is lowered to contact its surface. The indicator will now show by its reading whether the radius is within the prescribed dimensional tolerance.

The *position* of straight surfaces, in relation

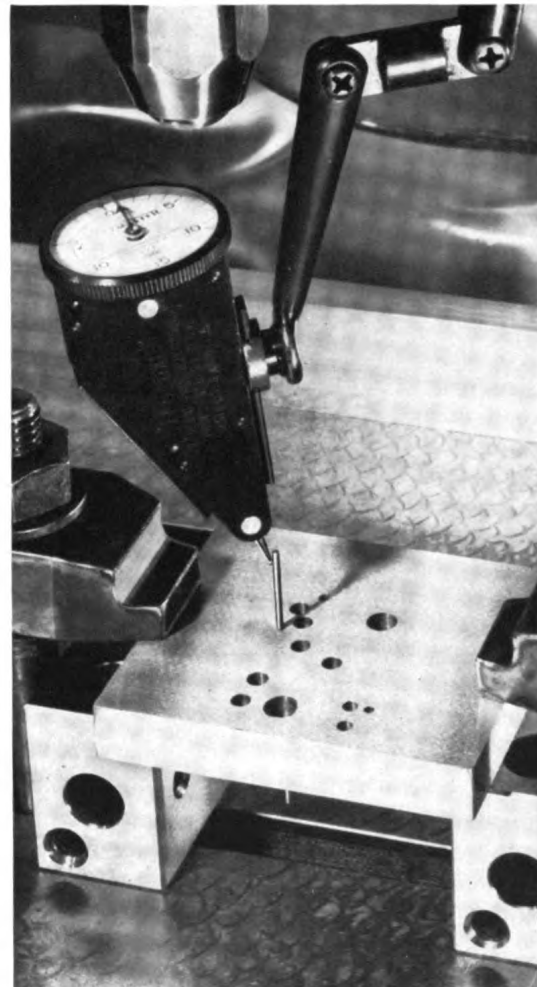


Fig. 289 — Lean of holes too small to probe with an indicator is detected by use of a fitted pin.

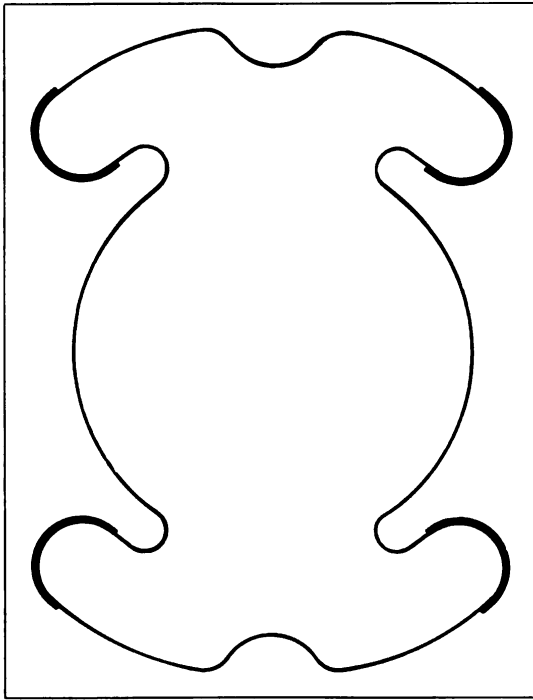


Fig. 290 — Four corner radii are ideal for pickup on this contour.

to the datum for the contour, can be verified by indicator measuring. Having set the indicator to the nominal value, the work is positioned to bring this datum or reference point in line with the spindle axis, and the indicator is brought in contact with the surface. Any deviation from the nominal position of the surface may now be directly read on the dial.

The accuracy of blend of radii to each other or to tangent surfaces is readily ascertained by positioning the axis of one of the radii in question in line with the spindle axis, and bringing the indicator into contact with its surface. This is slowly rotated and should show no change of reading until the blend line is reached. Continuation of this swing, in the case of a large female radius blended to a smaller one, as in Fig. 291, will show a uniform decrease in reading if they are accurately blended. A sudden drop or rise of the needle will reveal an error in blending at this line. This technique is equally applicable to the inspection of blend of radii

to tangents, male to female radii and large to small radii, either male or female.

The *alignment* of straight surfaces which nominally coincide with a direction of machine travel can be inspected by indicating such surfaces as the work is traversed by table movement. Alignment error is thus revealed by change in indicator reading. Surfaces *not* aligned with machine travel require the work to be mounted on a rotary table for inspection. The rotary table is set to the nominal angular displacement which aligns the surface with the travel. Alignment is then inspected, as in the preceding case.

The sharpness of corners formed by the intersection of surfaces can best be determined by the use of the microscope mounted on the machine spindle, Fig. 292. The conveniently graduated, concentric circles in the reticle help detect and measure any radius at the point of intersection.

**Screw Thread Inspection** — It would be fruitless to attempt a description of appropriate inspection procedure for the wide variety of work which, although it was not produced on the Jig Borer or Jig Grinder, can be effectively inspected by them. However, one type of inspection problem is common enough to warrant discussion. This is the ever-troublesome measurement of pitch, or lead, of screws,

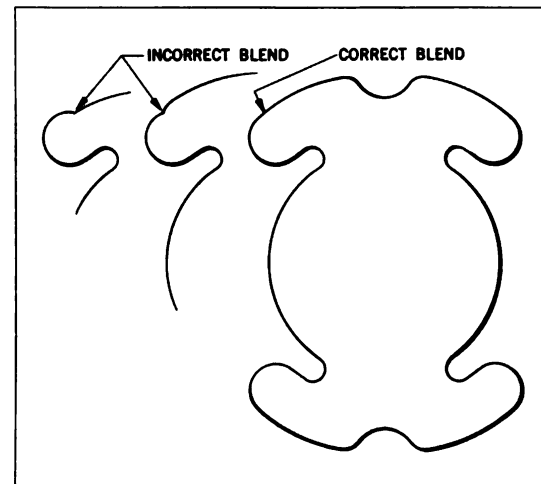


Fig. 291 — Jump of indicator needle shows lack of blend between radii.



*Fig. 292 — The microscope is ideally suited to inspection of minute corner radii.  
Inset shows corner as seen through eyepiece.*

taps, worms and hobs. While the screw will be cited as an example, all that applies to it is equally applicable to other related work-types mentioned.

The inspection setup is most conveniently made in a pair of matched V-blocks, carefully aligned with the longitudinal travel of the machine, Fig. 279. The straightness of the major and effective thread diameters is determined by simple measurement over wires before resting the screw in the V-blocks. Any bow should be oriented in the horizontal plane, where it will least affect the accuracy of the readings.

The table is positioned transversely to center the thread axis in line with the spindle axis. This can be done by indicating both sides

of the screw. The indicator is then brought in contact with the flank of the first thread, at approximately the pitch line, Fig. 293. The positive depth stop is locked and the indicator dial set to zero. The dials and scales of *both* travels of the machine are set, and the indicator re-checked, before proceeding with the actual measurement.

Lead is measured from this starting point by the following steps:

1. Back off the cross travel screw far enough to bring the indicator point clear of the work, Fig. 294.
2. Advance the longitudinal travel by an amount equal to the nominal pitch of the thread being inspected, as read on the machine's lead screw dial.

3. Re-set the cross travel to that reading representing the center line of the screw. This will bring the indicator into contact with the flank of the second thread at the pitch line. Any deviation from zero on the indicator represents the error in pitch between these two threads.
4. By repetition of these steps in sequence, accurate measurement can be made of lead for each successive thread, or as many as required.

The choice of cross movement of the work rather than vertical movement of spindle and indicator, to clear the latter, is dictated by the fact that in almost every type of thread, the *helix* angle is far less than the *flank* angle. Therefore, failure to exactly repeat settings in the case of vertical movement will introduce a greater error than in the case of cross movement, Fig. 295.

**Expression of Tolerance** — Much of the prevalent confusion and misunderstanding regarding the interpretation of tolerance, in its various forms of expression, should be dispelled.

The root of the problem in expressing tolerance seems to rest in failure to differentiate between *location* and *measurement*. A form of expression which might be appropriate for one may be ambiguous when applied to the other. Tolerance must be expressed in a form suitable to that which it *limits*, be it a linear

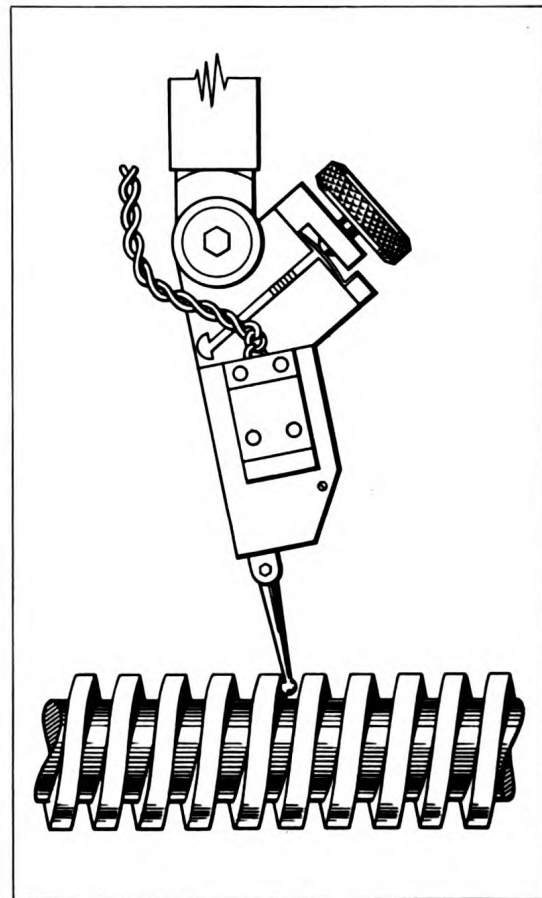


Fig. 293 — Picking up first thread of screw.

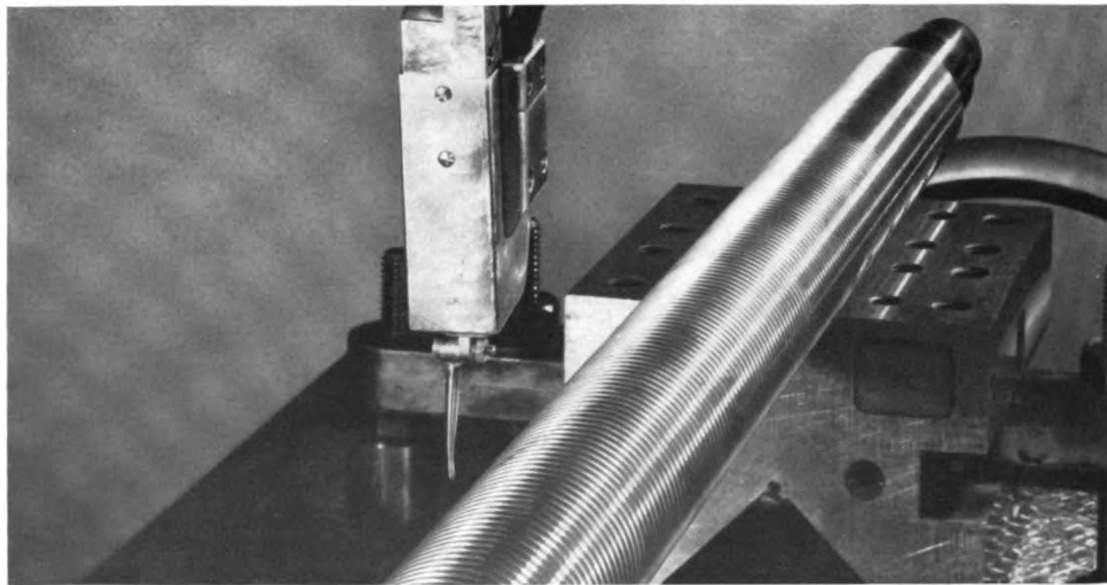


Fig. 294 — Work must be cleared by table movement before indicating adjacent thread.

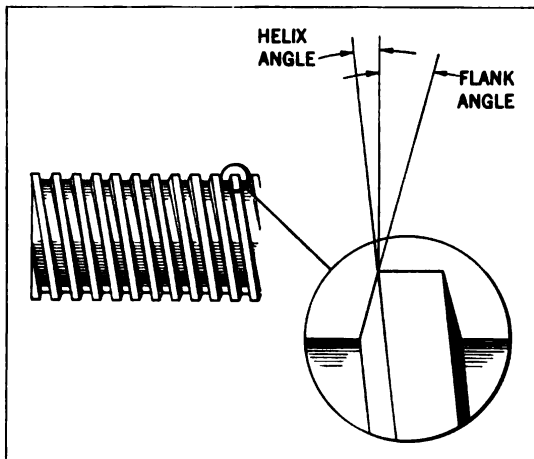


Fig. 295 — Relationship of helix angle to flank angle.

dimension, angular measurement or location!

In the case of a tolerance of location, an additional factor is introduced, the *true* position from which displacement is permitted, within the limits of the tolerance. This is designated T.P. and is, itself, related to some arbitrary datum, or reference, by a nominal dimension, Fig. 296.

The form of expression  $\pm .0001$  in this case would invoke the question, "From which, the

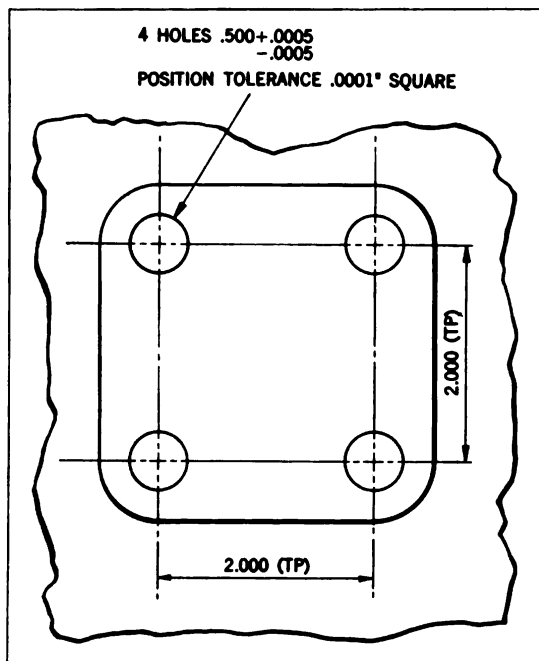


Fig. 296 — Use of T.P. in dimensioning locations.

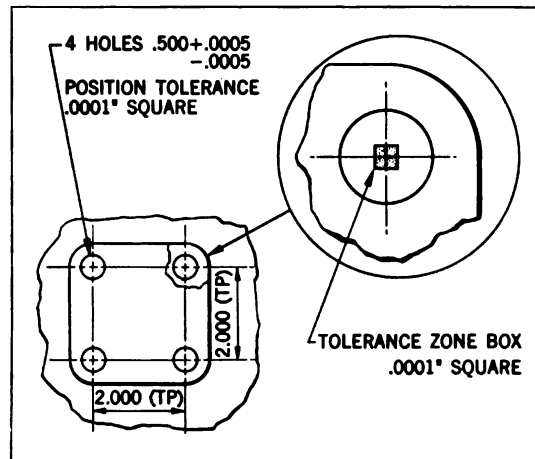


Fig. 297 — Graphic representation of tolerance zone.

true position or the datum?" Furthermore, it could at best be applied only in a rectilinear pattern.

In the interest of clarity the so-called "zone of tolerance" has much to recommend it.

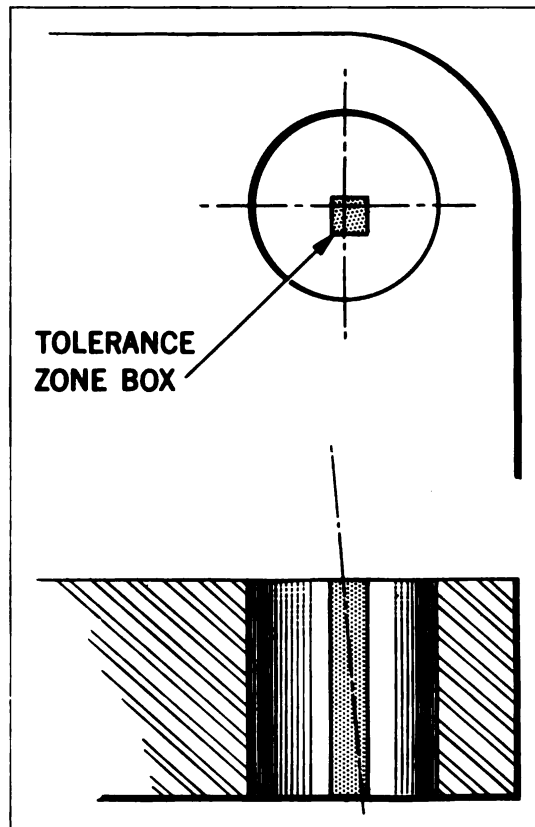
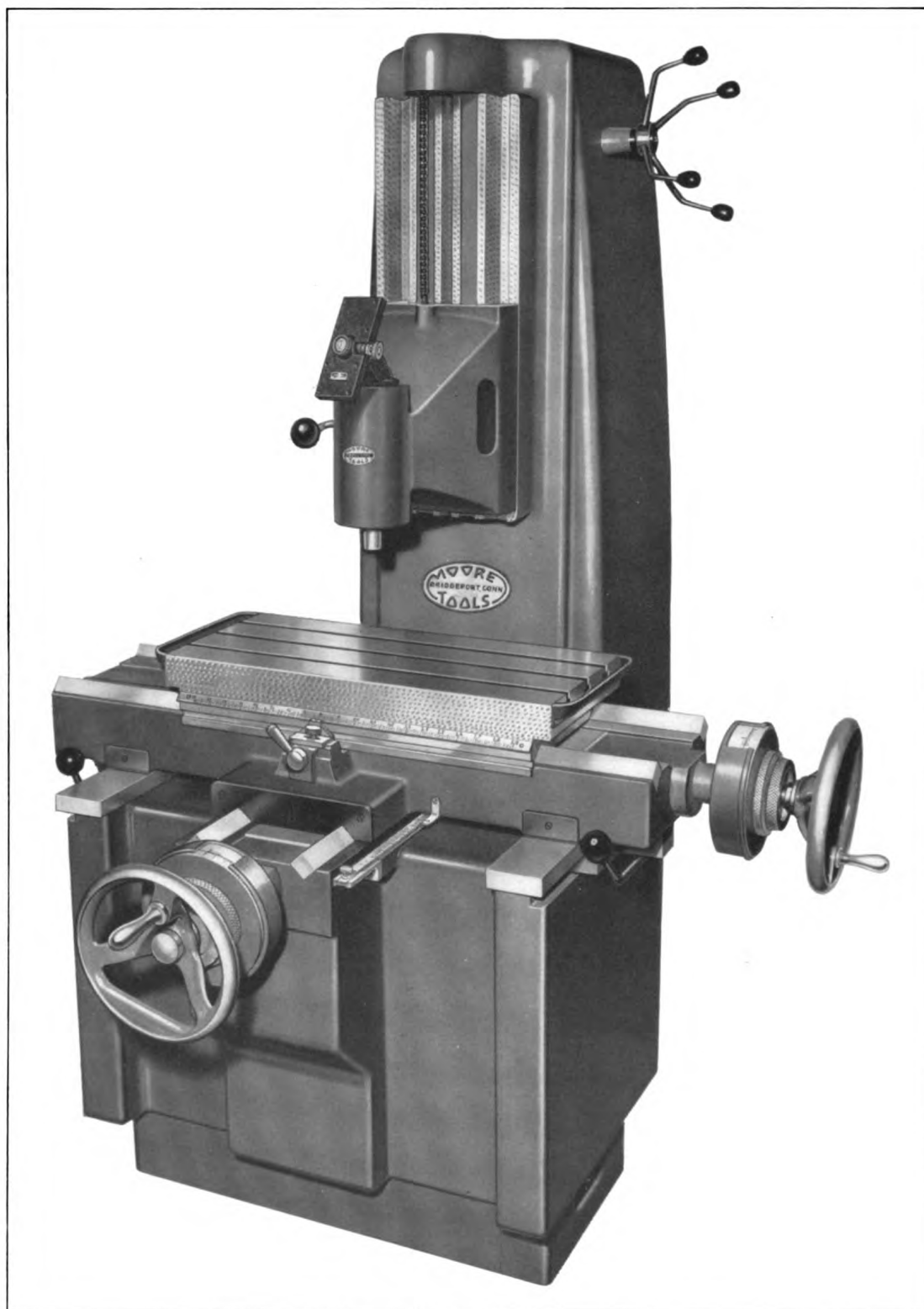


Fig. 298 — Relation of hole to its tolerance zone.



*Fig. 299 — Moore Measuring Machine.*

This "zone of tolerance" is, in effect, an imaginary rectangular box surrounding the T.P. By its dimension, it establishes the area within which the location in question must fall, Fig. 297. Several advantages are seen in this concept, including:

1. It not only limits the *area* of location but, because it has depth, it also limits geometric deviations, such as taper and angular inclination to the surface of the work, Fig. 298.
2. It corresponds to the normal distribution of errors.
3. It simplifies the tolerancing of complicated parts and the assignment of *different* tolerances to a number of locations on the same part.
4. It is compatible with the coordinate measuring system, and therefore directly adaptable to inspection by machines such as the Jig Borer and the Jig Grinder.

It is therefore proposed that in principle, tolerances of location be expressed as shown in Fig. 297; or if not so written, at least so visualized.

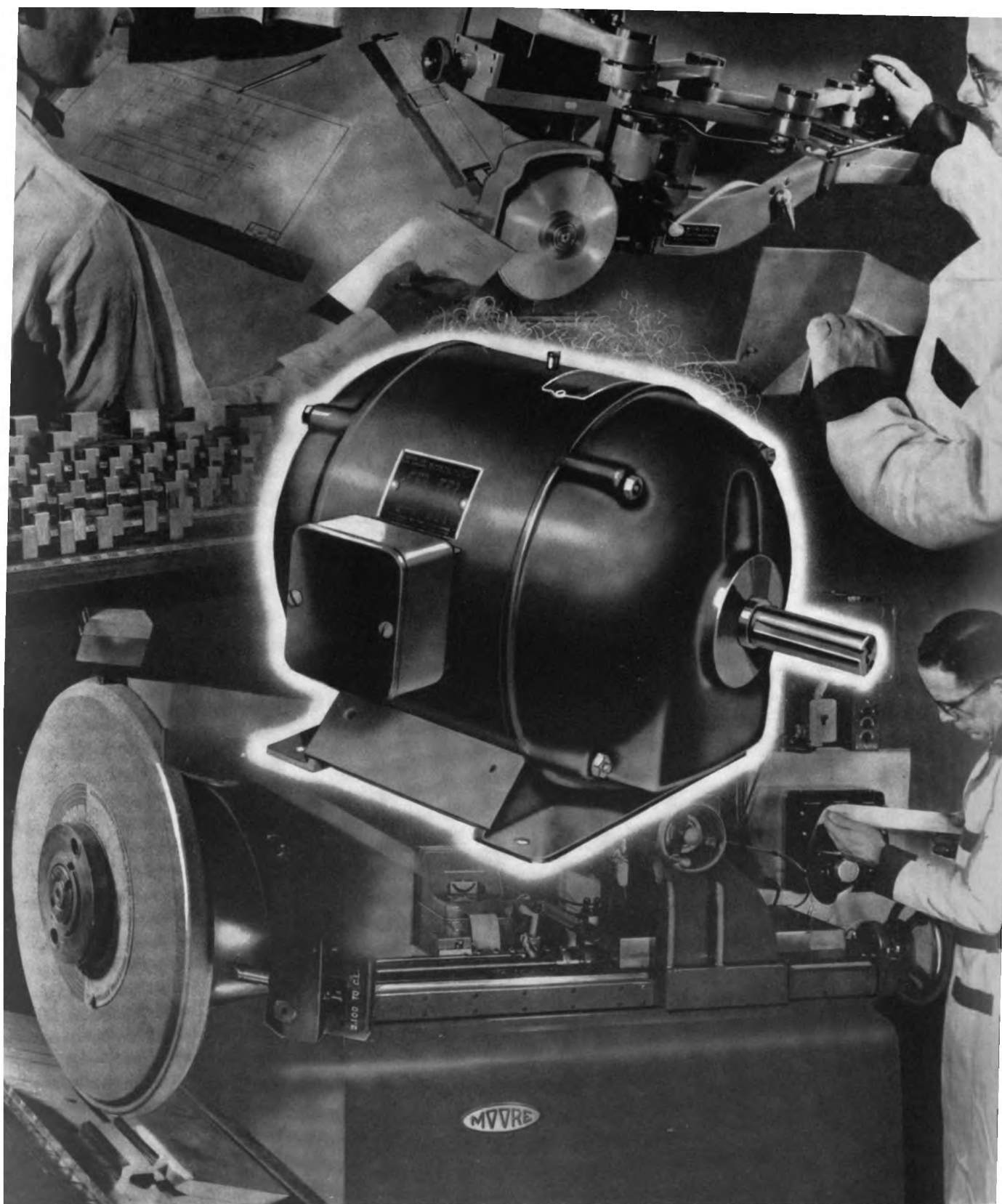
**Measuring Machine Inspection** — The Moore Universal Measuring Machine, Fig. 299, was developed in response to a demand for a rectilinear inspection device capable of the

ultimate in accuracy and adaptability in meeting virtually any inspection problem. This need has been exemplified by the number of Moore Jig Borer installations made solely for inspection purposes.

While, in the interest of convenience and efficiency, Jig Bored and Jig Ground work should be inspected while still in the machine, the Measuring Machine may be considered as a "Supreme Court," capable of rendering final verdict where verification of dimension is required to within *less than a "tenth."*

Designed in the same general character and incorporating the basic principles of the Jig Borer and Jig Grinder, the Measuring Machine employs, in inspection, the techniques outlined in this chapter.

In summation, it may be said that the Jig Borer and the Jig Grinder have established their ability to accurately and efficiently inspect *any* work which has been produced by them, as well as a wide range of work which has *not*. Where their capacity is taxed productively, inspection of work in the latter category may be more logically routed to the Measuring Machine, which serves as a final authority of accuracy.



*Specially engineered equipment for precisely locating holes, contours and surfaces pays dividends in the form of economical fabrication and a superior-performing end product.*

## PRECISION PAYS DIVIDENDS

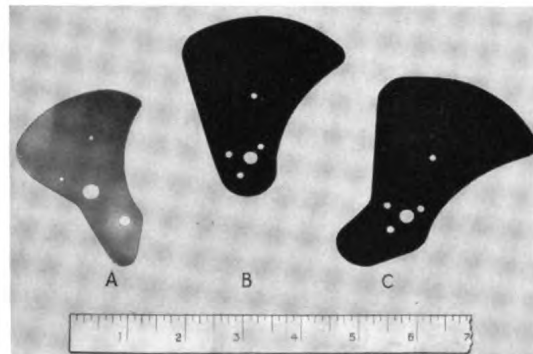
WITH the availability of equipment specifically designed to precisely and efficiently locate holes, contours and surfaces, there is no longer a need to compromise efficiency for accuracy in these operations. Then, too, painstakingly slow performance of these operations is, in itself, no assurance of accuracy; it may easily boost the cost of the attainable accuracy to a point where it is economically unjustifiable. On the other hand, the rapidity and accuracy of location and sizing of holes, contours and surfaces by the methods described in the preceding chapters provide adequate justification for working to figures instead of to fit. The advantages thus derived are reflected in both the economics of fabrication and the performance of the product.

The aspect of dependability or predictability of service life of tools is infrequently considered as a specific point in their evaluation. Yet this point is vitally important to the ultimate user of the tool, and consequently to the reputation of its producer. Apparent initial accuracy and a frequently false indication of service life can result from such toolmaker's tricks as staking punches, scraping punch plates or shifting strippers, to compensate for locational errors. Any of these expedients is certain to result in something less than the maximum potential life of the tool.

The justified confidence that can be placed in an all-ground tool made to figures is a very tangible value to the user, vastly minimizing the risk of interrupted production, down-time

on presses and costly repairs. Then, too, broken parts can be replaced with a minimum of cost and delay, due to the complete interchangeability resulting from this method of fabrication.

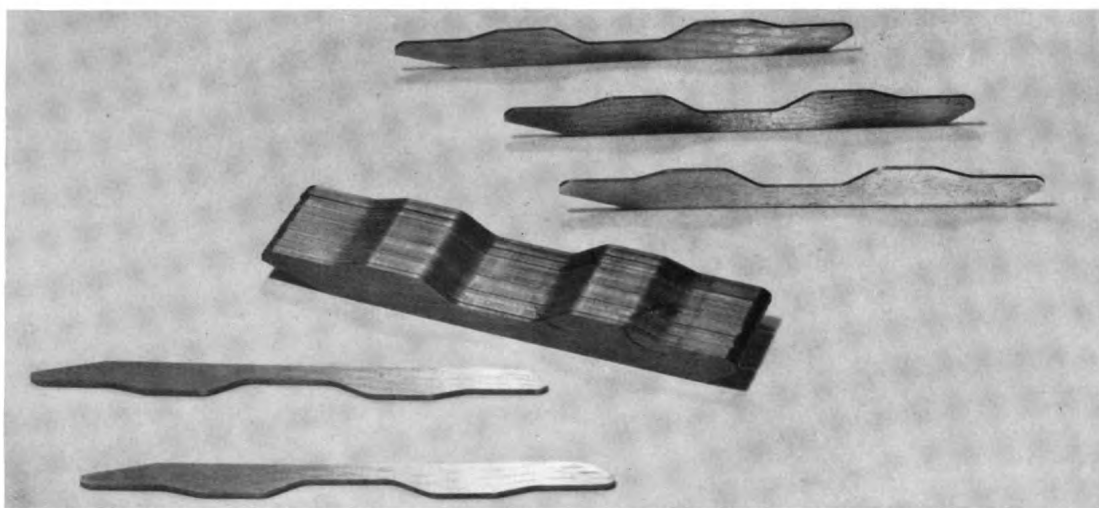
During manufacture of the tool, particularly in the case of dies, work can proceed independently on all parts, thus greatly shortening delivery time as compared with the toolmaker method of making parts to fit each other. Several months can be gained in the case of precise, complicated tools, Figs. 300 and 301.



Courtesy of Koller Die & Tool Co.

Fig. 300 — Blank A is of a special .003" aluminum foil; blanks B and C are of .006" spring steel. No burr was permissible on the contour or at the pierced holes. Punch and die were made to the same set of figures which were trigonometrically pre-established. The dies were compound, with the stripper and shedder ground flush with the punch and die, respectively, in order to return the blank into the scrap. The punch holder, as well as the piercing holes in the blanking punch, were Jig Ground to assure perfect alignment of the piercing punches.

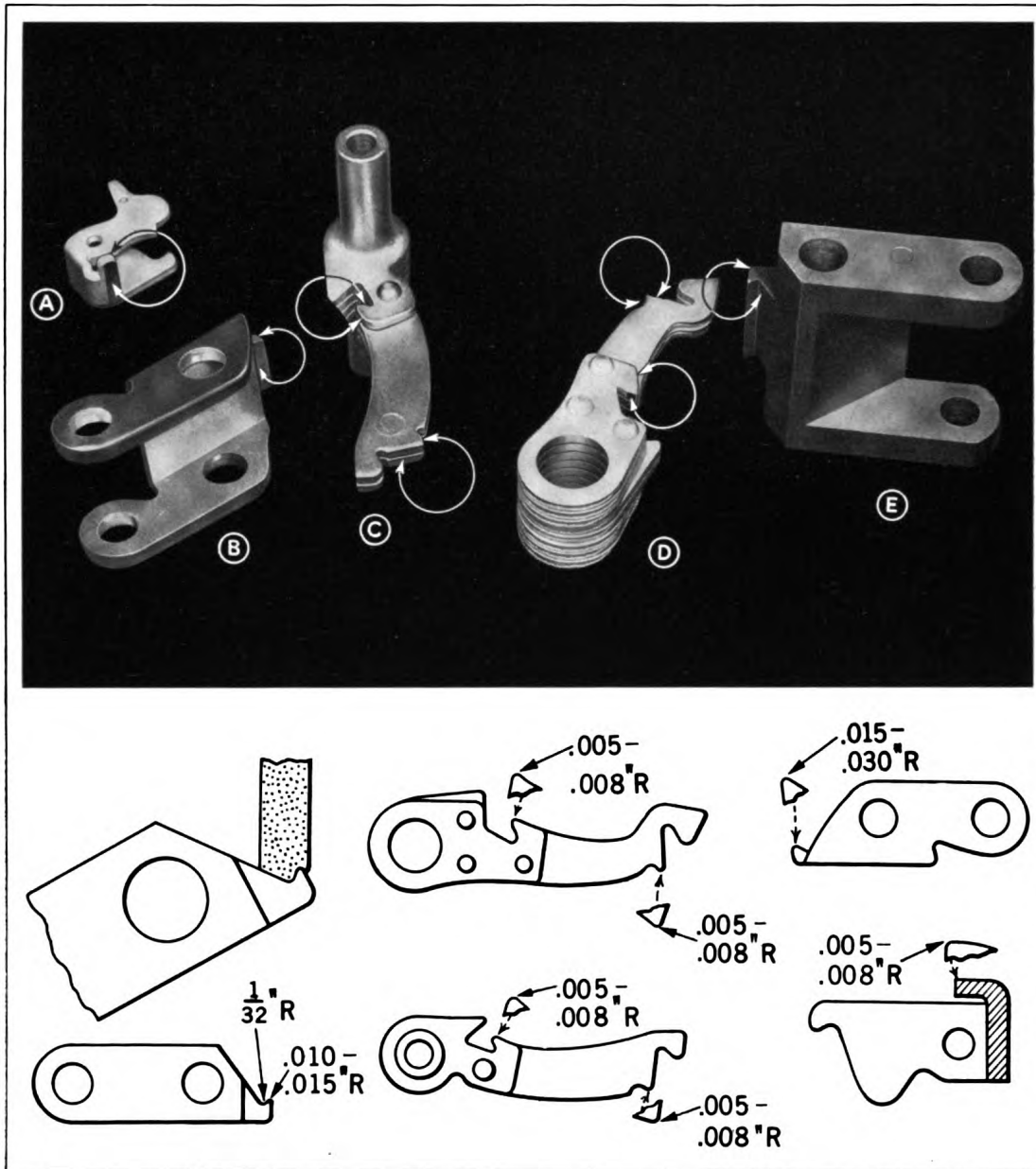
## HOLES, CONTOURS AND SURFACES



Courtesy of Harig Manufacturing Corp.

*Fig. 301—Both the production lots of blades (above) and injection molding die parts (below) for pens and pencils represent work most efficiently produced by the formed-wheel method of contour grinding.*





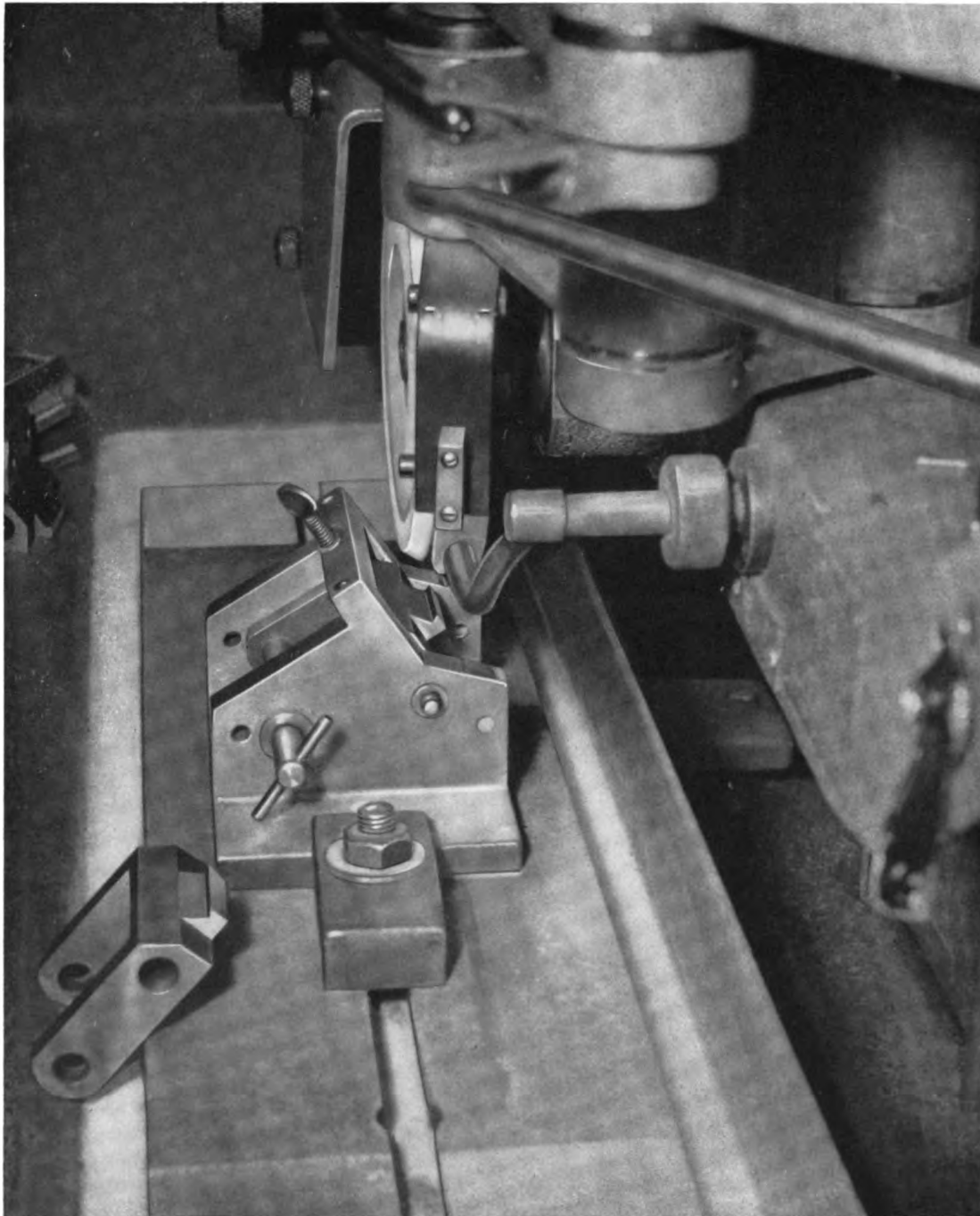
Courtesy of I-T-E Circuit Breaker Co.

Fig. 302 — Five main latches for various patterns of I-T-E circuit breakers have either one or two “hooks,” which must be ground accurately to obtain proper dropout action. Time savings through form grinding are: Part A—33%; part B—31%; part C—42%; part D—10%; and part E—32%. Further savings in assembly are also obtained because no time is lost with hand fitting in order to get the desired action of the circuit-breaker mechanism.

The significance of these factors has led several of the large-scale users of high-production press tools to include in their specifications that all tools quoted must be Jig Ground. Unquestionably this is the be-

ginning of a trend which will ultimately become a standard for high quality tools. Only in this way can the purchaser be certain of the quality of the tool he buys.

Indicative of this trend is the establishment



Courtesy of I-T-E Circuit Breaker Co.

*Fig. 303 — Radius, fillet and flat surfaces are all ground at once with the formed wheel to a surface finish of 4 to 6 micro-inches. Dressing of the form on the wheel is controlled by a Moore Panto-Crush Wheel Dresser.*

of a number of shops throughout the country offering the toolmaking industry Jig Boring and/or Jig Grinding service. One such shop keeps seven Jig Borers busy on contract work, while another employs four Jig Grinders similarly. This represents one further step in the philosophy of specialization, and clearly demonstrates that there is an increasing aware-

ness of the significant advantages of efficiently attaining a high degree of locational accuracy.

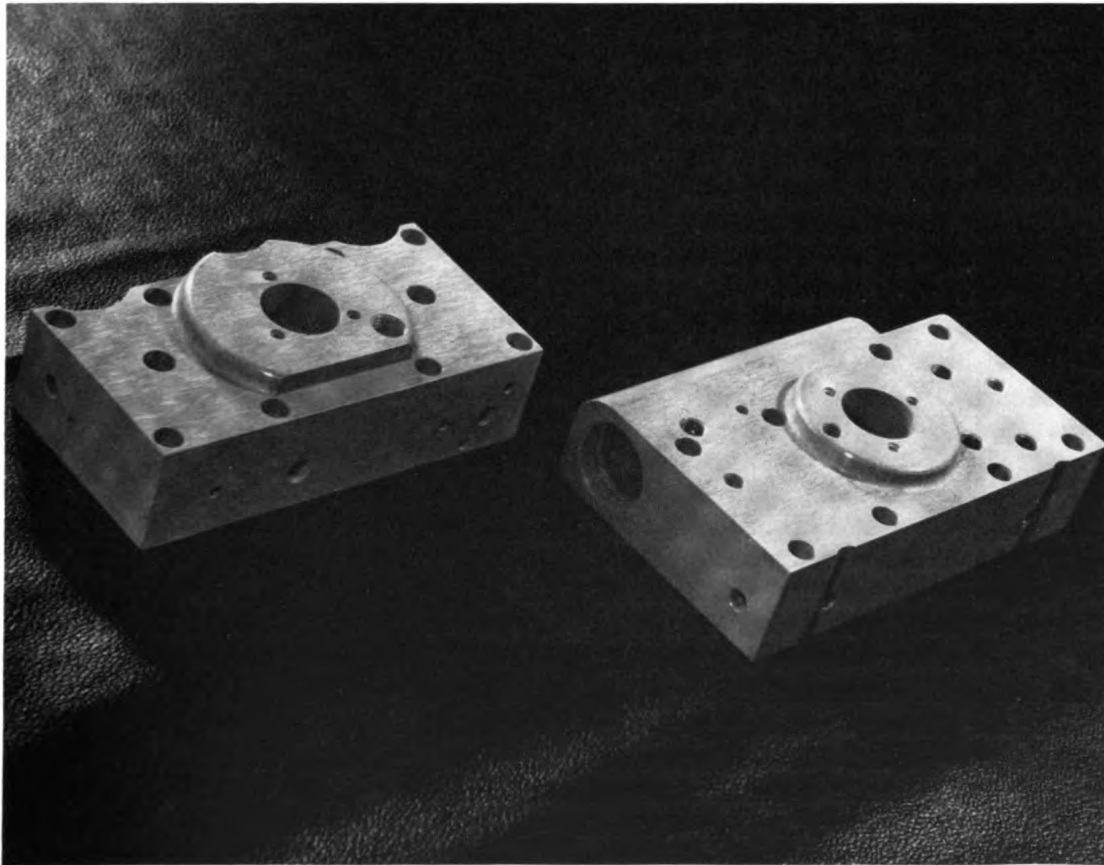
Alternatively, innumerable smaller tool shops, having insufficient work to fully utilize the capacity of a Jig Borer or Jig Grinder, keep the machine and operator occupied by taking in a limited amount of outside work. In this way the machine may be made to justify itself economically, and the operator retains his most efficient status as a specialist.

### FORM GRINDING LATCHES

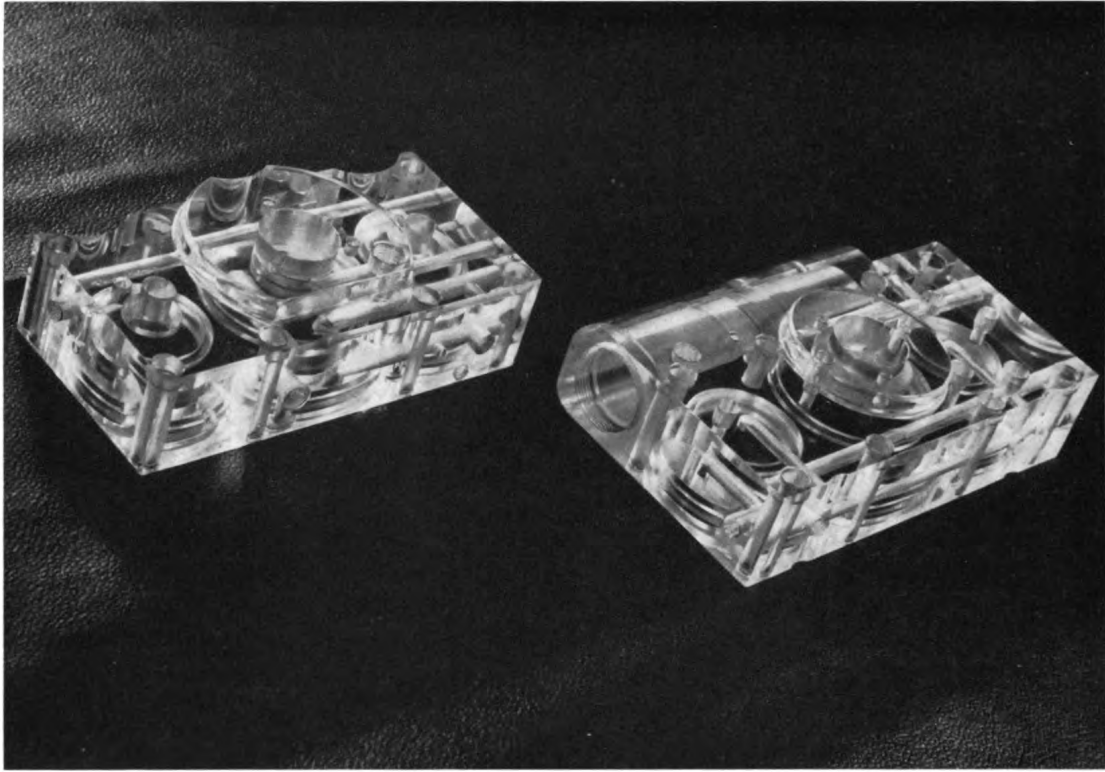
In circuit breakers it is difficult enough to obtain rapid, arc-free action in extremely short time intervals without being plagued by sluggish action of mechanical elements. For this reason, the main latch of the trip mechanism must have several surfaces, a radius, and perhaps a fillet, on the hook section, properly ground and blended, Fig. 302.

But even though the latch might be considered the heart of the mechanism, until recently the I-T-E Circuit Breaker Company was compelled to grind separately the several related surfaces and a radius, and to do some hand work on the parts. Thus, while each circuit breaker functioned properly when it left the factory, interchangeable latches were not available to simplify assembly and field service. The latter was a problem.

The decision to apply what had been considered a toolroom method of form grinding to manufacture of main latches is a typical example of how I-T-E operates. This medium-size independent manufacturer has for years demonstrated its faith in maintaining a modern shop by spending hundreds of thousands of dollars annually for replacement equipment and tooling. Its management says: "Any machine, regardless of age, will be replaced



*Fig. 304 — Little of the internal complexity of these aluminum manifold blocks is apparent in this illustration.*



*Fig. 305 — Reproduced in transparent plastic by the same machining methods used for the aluminum, these models permit visualization of the production problems involved.*

by a more productive one; any process that is unchanged after five years is subject to suspicion." This attitude is remarkable, considering the fact that most of I-T-E's many thousands of operations are conducted on a small-lot rather than a mass-production basis.

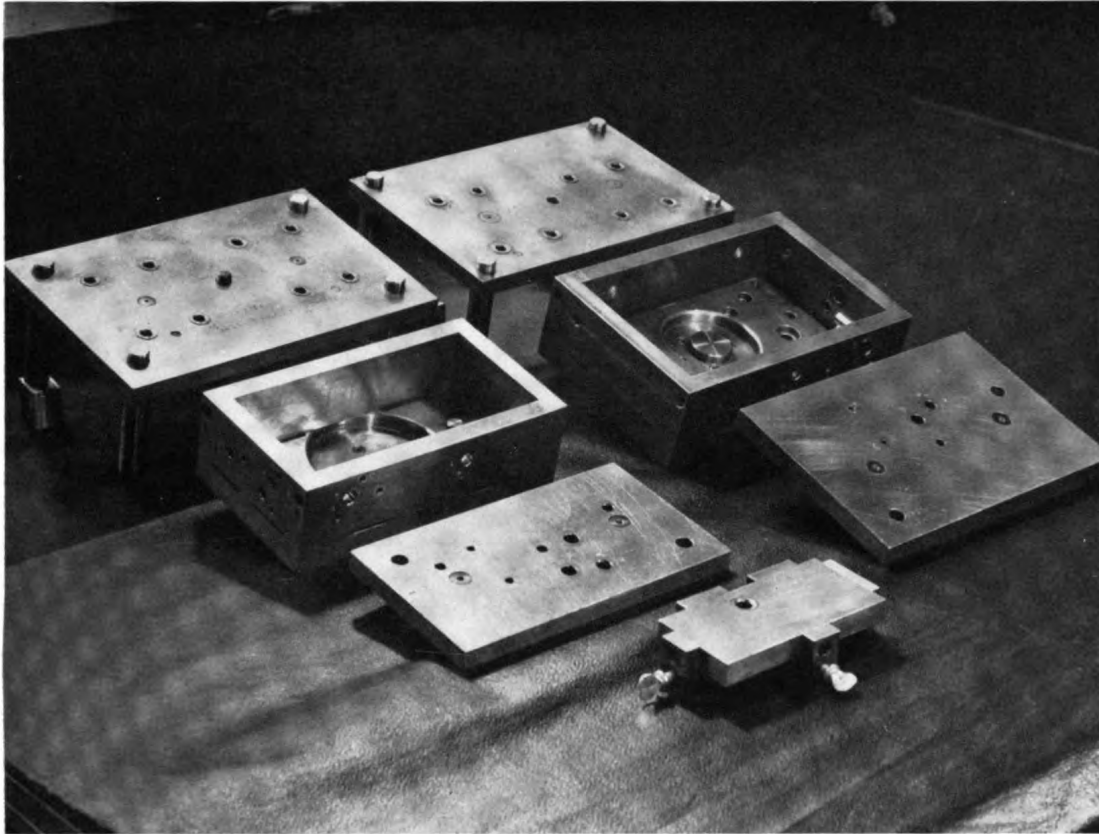
No machinery-replacement formula or special practices are used to determine whether a new machine will save production time. Executives responsible for production and equipment constantly visit various departments to study operations and processes, and to visualize the potential savings from both a new machine and appropriate tooling. And they encourage vendors to inspect operations and make recommendations.

This policy, in respect to form grinding of main latches, has paid off in an average time saving of 30 per cent, plus product improvement that gives better calibration of circuit breakers and achieves a uniformity in operation never previously attained by hand fitting.

Further, the interchangeability of latches, both in assembly and field replacement, has definite advantages.

Form grinding is done on No. 2 Brown & Sharpe surface grinders equipped with a Moore Panto-Crush Wheel Dresser attachment. But the wheel is not crush-dressed to form, because it is said that the "grain cannot be split" by such means, and hence the work finish would not be satisfactory. So the wheel is dressed to form with a diamond stylus, whose movements are controlled with a pantograph tracer bearing against an enlarged template of the work profile. A 10:1 reduction is obtained from the pantograph.

Prior to form grinding, the pivot hole in the main latch is ground on a Bryant grinder to .0005" or better, to provide a locating surface. During form grinding, the part is held in a simple fixture with a pin passing through the ground pivot hole. The part is located in the fixture in a position so that all



*Fig. 306 — Non-critical holes are efficiently drilled in jigs.*

surfaces can be ground without necessity for dressing re-entrant angles on the wheel. With a 100-grit, G-bond wheel, a surface finish of 4 to 6 micro-inches is obtained and wheel wear is satisfactory, Fig. 303. This surface quality much improves the smoothness with which the latch disengages from the detent mechanism of the circuit breaker.

#### **JIG BORER UTILIZATION**

The two aluminum manifold caps, Fig. 304, and their plastic models, Fig. 305, represent a typical example of the uses of a Jig Borer from model work to production, a theme originally introduced in Chapter 6. Used as machine parts in a hydro-pneumatic system, they require a high degree of geometric, locational and dimensional accuracy in almost every detail of their intricate internal configuration. The numerous holes, bores, undercuts and intersections in several planes

serve to locate valves, packings, piston rods and cylinder liners, as well as to carry oil and air under high pressure.

The first pair of caps were machined complete from aluminum bar stock on the Jig Borer, including all milling, drilling, tapping, boring, reaming, undercutting and counter-boring. Due to the complexity of circuitry, holes were required to intersect or avoid each other by very close margins. In some instances the tendency of deep-drilled holes to wander slightly made it necessary to re-locate them to avoid possible future difficulty in production. At this stage this could be done conveniently, since no tooling was involved and those holes which controlled interchangeability with future lots were unaffected.

Having been proved by installation on the prototype machine, it became necessary to start production of these parts immediately. Since tooling would not be available in time,

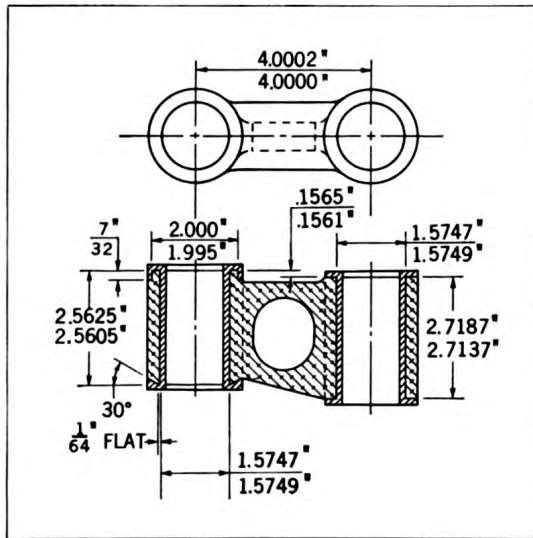


Fig. 307 — The time required for machining the cross-hatched areas of this aluminum-alloy part was reduced from  $3\frac{1}{2}$  hours for each piece to 22 minutes apiece by use of a Jig Borer.

and to insure interchangeability with future-tooled production, a number of these parts were produced complete on the Jig Borer.

Concurrently, the tooling for the parts was being Jig Bored and assembled. This consisted of a variety of drill jigs and fixtures, Fig. 306, to provide for future drilling, tapping, reaming and counterboring of those holes which did not require a high degree of locational accuracy.

Anticipating the drill press operator's problem in following the necessarily complicated parts drawings, and as insurance against possible work spoilage, the idea of the transparent plastic models, Fig. 305, was conceived. Produced on the Jig Borer exactly as were the first aluminum parts, these models have proved valuable as a visual guide for each operation performed on the production lots — and they are still in constant use for this purpose!

In the production plan ultimately adopted, all of the significant bores and recesses are Jig Bored to attain high accuracy and to provide locating points for the drill jigs and fixtures used in subsequent operations.

The advantages of the Jig Borer concept

throughout this typical job, from design considerations to use in production, are vitally important. Summarization reveals:

1. The first piece of each part was produced in a fraction of the time and at a much lower cost, but to a higher degree of accuracy than possible by any other method.
2. Necessary minor changes in the location of some of the holes in the parts were possible *without involving changes in tooling*. This did not affect locational interchangeability with future-tooled production parts.
3. Early production lots were completed entirely on the Jig Borer, without waiting for tooling to be made.
4. Tooling, including drill jigs and fixtures, was made concurrently with the Jig Boring of the first lot of parts.
5. Transparent plastic models of both parts were made on the Jig Borer, proving the suitability of the tooling and providing a visual aid to machine operators.

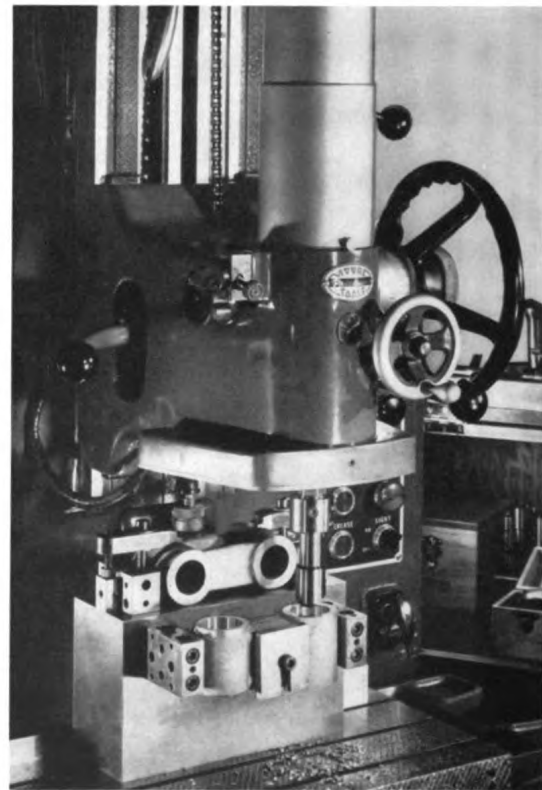


Fig. 308 — In this Jig Borer setup, a simple fixture is used which provides a milling position and a boring position for machining the part illustrated in Fig. 307.



*Fig. 309 — After finish-boring two boss holes to a total tolerance of .0002", the hole sizes are checked on the Jig Borer.*

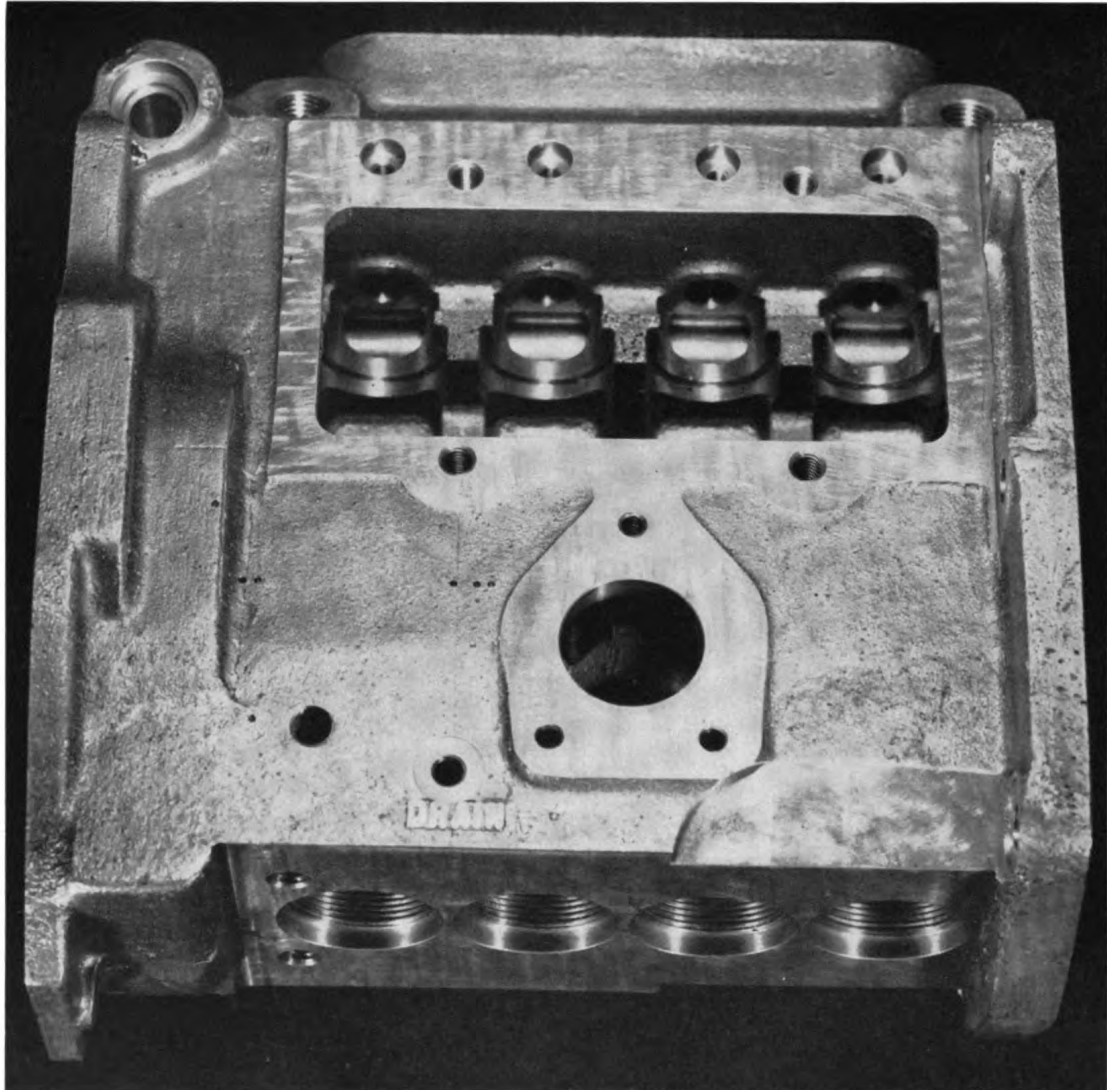


*Fig. 310 — Examples of parts completely machined in lots of 100 on a Jig Boring machine.*

6. Since accuracy beyond that possible in a drill jig is required in certain holes and recesses of both parts, these continue to be Jig Bored in production.

#### PRODUCTION JIG BORING

Small manufacturing shops engaged in short-run production of precision work, as well as large plants which produce interchangeable parts on a quantity basis, make extensive use of Jig Boring machines. These machines are widely employed for boring, drilling, reaming and inspecting precisely located and machined holes both in production parts and in such tools as dies and jigs. A typical production job performed on a Jig Boring machine is described in the following.



Courtesy of American Bosch Mfg. Co. and B and E Tool Company

*Fig. 311 — Cast aluminum Diesel injection pump body completely machined on a Jig Borer.*

The part illustrated in Fig. 307 is an aluminum-alloy supporting arm. The dimension between the centers of the holes in the two bosses is held to a total tolerance of .0002". Precision bearings are installed in these holes so that their diameters are also held to the same tolerance.

Originally, this part was machined on a boring mill. The webs between the bosses were first milled to form locating surfaces, after which the work was clamped on the boring mill for machining the surfaces indicated by cross-hatching in Fig. 307. The time

required for machining each part in this manner was  $3\frac{1}{2}$  hours.

Performing the same operations in the Model No. 2 Jig Borer takes approximately one-tenth the time previously required. As may be seen in Fig. 308, a simple fixture holds two parts in this machine. One part is positioned for milling the ribs, and the other for boring. Beginning with milling, ten operations are performed on each of 100 pieces. The milling operations are accomplished by a single-point fly cutter, held in a  $2\frac{1}{2}$ " solid boring bar, using a spindle speed of 1,000



Courtesy of Lycoming Division of Avco Manufacturing Corporation, Bridgeport, and Tippet Jig Bore Company

*Fig. 312 — Radial plunger-type gage for aircraft engine components.*

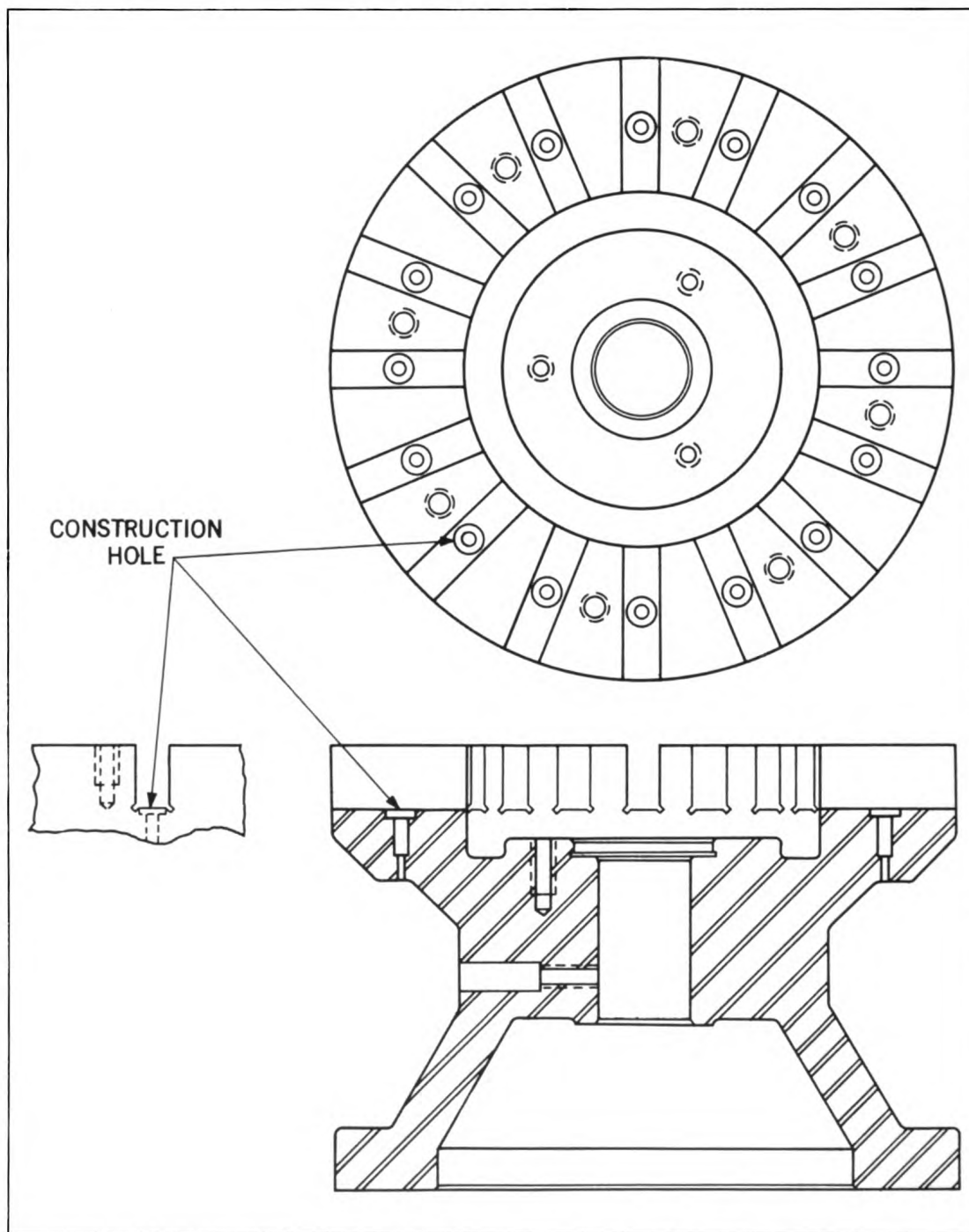


Fig. 313 — Section through gage, showing construction details.

rpm. Next a carbide boring bit, mounted in a  $1\frac{1}{4}$ " solid boring bar, is used to rough-bore the two boss holes at a spindle speed of 2,000 rpm, using a feed of .015". The two top sur-

faces of the bosses are then rough-faced with the same tool as was used for milling the ribs, after which the work is removed from the fixture and allowed to cool to avoid distortion.

A second rough-boring operation in the two holes is now performed. For this operation, the boring tool previously used is employed at a spindle speed of 2,000 rpm, with a feed of .003". The finish-boring of these holes is done with a carbide boring bit, held in a 1¼" micro-setting bar. A feed of .015" and a spindle speed of 2,000 rpm are used. The holes are then checked for size, as illustrated in Fig. 309.

After checking, a 1½" sweep tool is used at a spindle speed of 800 rpm for roughing and finishing the 30° bevel at the bottom of one boss. The bottom face of the other boss is roughed and finished in the next operation with the same tool and spindle speed. Then, using an "outfeed" chuck, a spindle speed of 800 rpm and a feed of .0025" per revolution, the two top surfaces of the bosses are finish-faced.

The final operation consists of roughing and finishing the shoulder of one of the bosses to between 1.995" and 2" in diameter. A 2" chuck is used in this operation at a spindle speed of 400 rpm. Including 4.5 hours for making the fixture, 6.5 hours for setup time and 22 minutes apiece for 100 parts, this production run was accomplished in 47.6 hours. Examples of completed parts are shown in Fig. 310.

In machining the aluminum supporting arms, the tools are changed to finish each part completely before the next one is handled. However, it is often desirable to perform certain operations on every piece in a run and set the work up again for subsequent operations. This may be advantageous where there are thin sections between machined surfaces on the parts, so that heat can be dissipated by rough-machining the complete lot before finish-machining. Generally, the design of the part determines the procedure.

The Diesel injection pump casting shown in Fig. 311 represents a typical example of the work a contract Jig Boring facility can perform to advantage for a large manufacturer. The pilot lot of eight of these aluminum castings was produced complete on the Moore Jig Borer.

In this way it was possible to quickly, inexpensively and accurately check out the design, pattern and performance before going into production tooling.

After rough milling, the castings were stress-relieved and all surfaces were squared and finished on the Jig Borer by fly cutting. All holes were finished by boring to size. Tapping was also done in the same machine to insure squareness.

### AIRCRAFT ENGINE GAGE

The gage for aircraft engine components shown in Fig. 312 represents a type of work-piece which might not, at first thought, be considered ideally suited to Jig Grinding. Further consideration, however, will reveal that this is virtually the only efficient and accurate method of establishing the location and size of the radial slots and related construction holes, Fig. 313.

Three gages comprising 10, 12 and 16 slots each were produced by the vendor for a large aircraft engine manufacturer. The contract was let on the basis that the job be done on a Moore Jig Grinder and a Moore Model No. 2 Rotary Table as an insurance of accuracy.

Significant factors controlling the accuracy of this gage are as follows:

1. All slots to be within .0002" of nominal size and alike.
2. Angular location of slots to be within .0002", total accumulated error.
3. The holes, centrally located in the slots, to be within .0001" of location.
4. Concentricity to be held to .0002" T.I.R. As produced, all gages came well within these tolerances.

The slots were Jig Ground by the wipe grinding technique (see page 145), index spacing being controlled by the inherent angular accuracy of the rotary table, without recourse to its calibration chart. The related holes in the bottom of each slot were Jig Ground to coordinate location.

At this point one might well reflect on the overall benefits to be derived from full implementation of the philosophy of "working

## HOLES, CONTOURS AND SURFACES

to figures instead of to fit" through the use of available engineered locating equipment. In the preceding chapters, each type of equipment has been discussed more or less independently, although the cumulative effect of the partner relationship is more realistically represented by the product rather than the sum of their individual advantages. Each complements and increases the value of the other, and together provide a unit facility for the precise location, machining and inspection of *all* holes, contours and surfaces. Thus there is no need for compromise with efficiency, no slipshod phase of the work to detract from the overall accuracy of the complete job. Since a chain is no stronger than its weakest link, it is important that one locating operation be no less efficient or accurate than another.

The intended purpose of this book has been threefold:

1. To outline the principles of Jig Boring, Jig Grinding, Contour Grinding, Form Grinding and Inspection.
2. To discuss sound practices for the above operations.
3. To develop the logic of the theory of interchangeability in working to figures instead of to fit—in toolmaking as well as on the production line—through the use of engineered locating equipment.

The best yardstick which may be used to gage the attainment of this multiple goal is the degree of help it may have provided for those who are confronted with the competitive problem of seeking greater accuracy and efficiency in the location of holes, contours and surfaces.



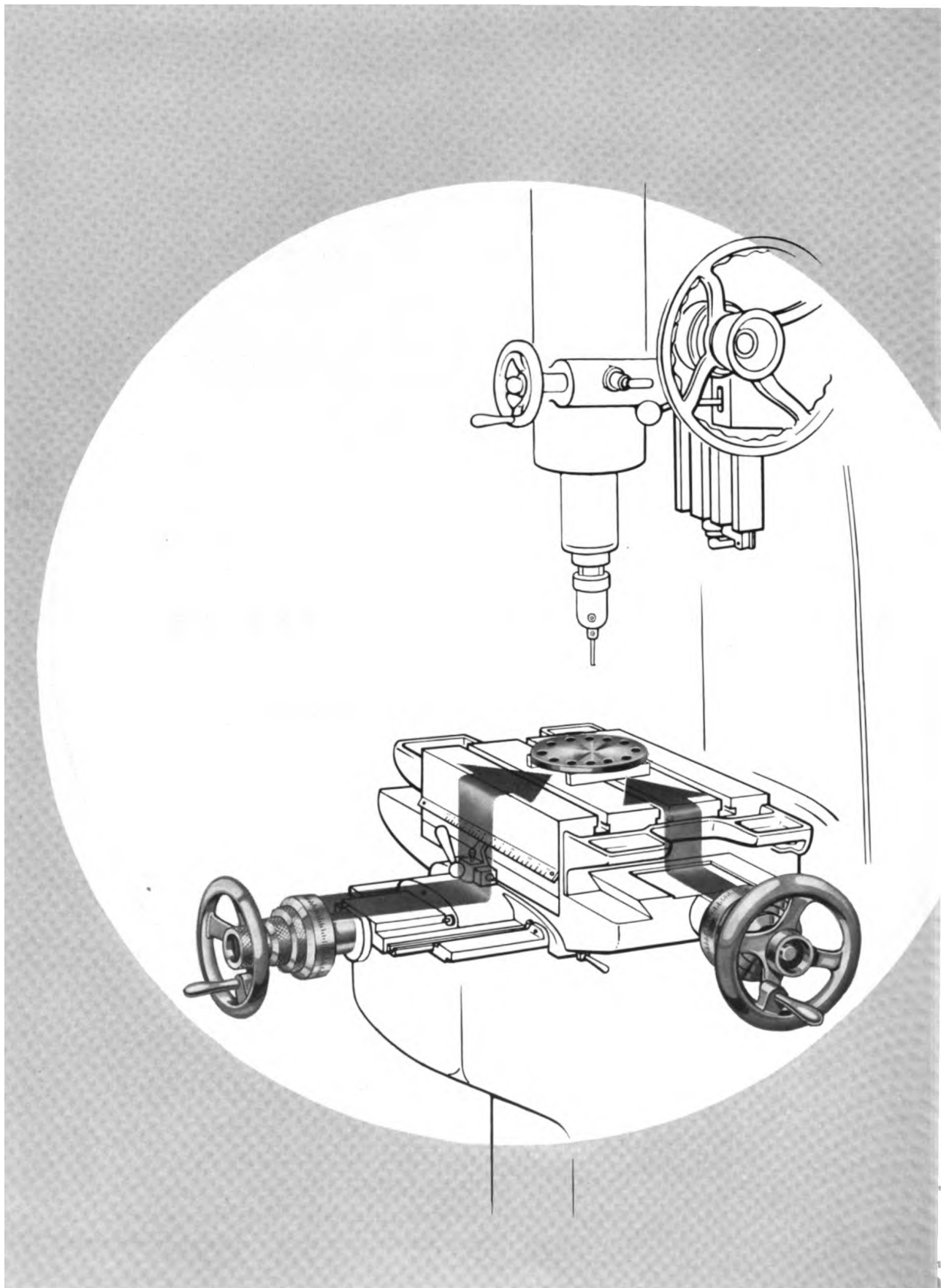
# **WOODWORTH CIRCULAR TABLES**

**OF COORDINATE FACTORS AND ANGLES**

*By* W. J. WOODWORTH

J. D. WOODWORTH

*Every effort has been made to assure accuracy in computing and publishing these tables. However, neither The Moore Special Tool Company nor the Woodworths can assume any responsibility for errors therein.*



*Partnership of Woodworth Circular Tables and accurate lead screws built into Moore Jig Borers, Jig Grinders and Measuring Machines speeds table settings.*

# INSTRUCTIONS FOR USING

## WOODWORTH CIRCULAR TABLES

**H**OLES ON CIRCLES may be laid out either in polar coordinates (angle and distance) or in rectangular coordinates. Polar coordinates, used with the rotary table, are undoubtedly the more convenient, and the easier to calculate. Rectangular coordinates, however, are inherently more accurate, due to the slight additional inaccuracies introduced by the rotary table principle (see page 77).

Calculating the coordinates in either case is no small job, especially when the number of holes is large.

Figuring the angles alone is a tedious, time-consuming operation, Fig. 314.

When calculating rectangular coordinates, figuring the angles is only part of the job. After the angle and distances are known, the distances from the center must be multiplied by the cosines and sines of the angles to reduce them to rectangular distances, which must be either *added to* or *subtracted from* the coordinates of the center of the circle to find the rectangular coordinates of each hole, Fig. 315.

W. J. Woodworth, of Mineola, Long Island, N. Y., a toolmaker, tool designer and tool supervisor of 48 years' experience, recognized the difficulties in these calculations. With his son, J. D. Woodworth, he set about developing tables to enable Jig Borer operators to obtain the correct figures with the least effort.

The cost-saving features of these tables have been thoroughly demonstrated over a period of ten years prior to publication in this book. Richard F. Moore, president of The Moore Special Tool Company, states: "It would be difficult to evaluate in dollars the substantial savings which have resulted from use of the Woodworth Tables in our toolroom. To say that they save their cost on a single job is a gross understatement."

Application of these tables to polar coordinates is obvious. The angle from zero to any hole, read directly from the tables, together with the radius of the circle, establishes the location of the hole.

Calculation of rectangular coordinates, even *with* the Woodworth Tables, is necessarily somewhat more complex than for polar coordinates, since it involves multiplication of the diameter of the circle by a tabulated factor. The diameter being a constant throughout the calculation for any specific circle, the work is very conveniently done in a calculating machine.

A comparison between Figs. 315 and 316, however, reveals that the use of this table results in an enormous saving of time, with less possibilities for error.

Use of the Woodworth Tables in calculation of rectangular coordinates is best explained by example, Figs. 317 to 320.

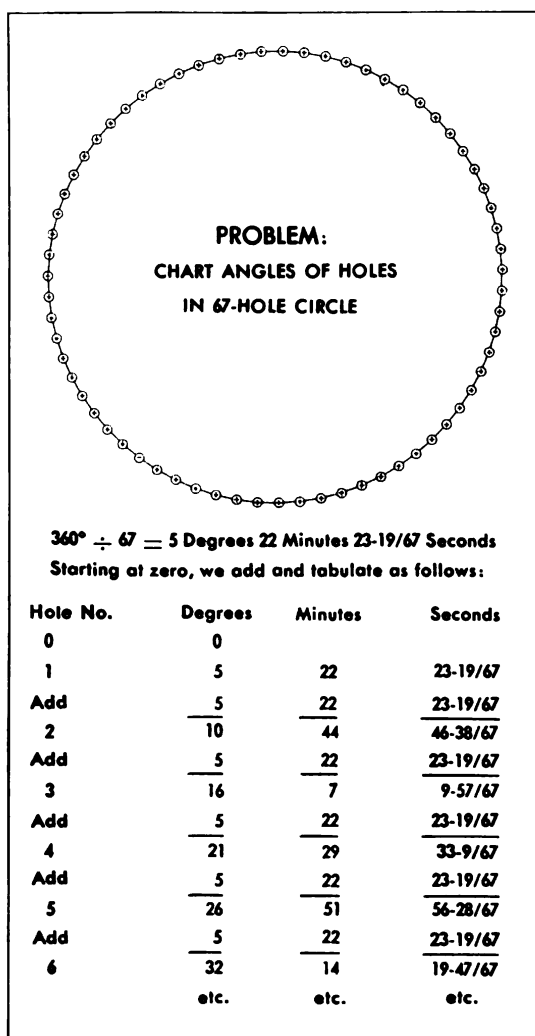


Fig. 314 — Steps required to calculate angular position of holes on circle. To prevent cumulative error each small fraction of angle must be added every time.

First, rectangular coordinates of dimensioned holes and center of divided circle are determined, Fig. 318.

Next, the coordinates are calculated for the *left-hand* and *upper tangents* of the divided circle by subtracting the radius of the circle from the coordinates of the center. Fig. 319.

Next, look in the 11-hole table for the A and B factors for each hole. Multiply these factors by the diameter of the circle of holes, and add their products respectively to the coordinates of the left-hand and upper tangents. Place these figures on the drawing as shown at hole

**Problem:** Calculating rectangular coordinates of holes on circle *without* Woodworth Tables:

1. Determine coordinate location, in both [directions, of center of circle.
2. Compute angle of each circular division as in figuring polar coordinates.
3. Determine quadrant in which each angle is located.
4. Find relation of each angle to horizontal line, by subtracting from  $90^\circ$ ,  $180^\circ$ ,  $270^\circ$ , or  $360^\circ$ , or vice versa.
5. Multiply cosine of angle by radius of circle.
6. Add or subtract result to or from coordinate of center of circle.
7. Multiply sine of angle by radius of circle.
8. Add or subtract result to or from coordinate of center of circle.

Fig. 315 — Steps in calculating rectangular coordinates of holes on circle without Woodworth Tables.

No. 8, Fig. 320. These figures represent the rectangular coordinates for hole No. 8.

Note that the dimensions in the tables are shown from the left-hand and upper tangents of circles. Adding is more convenient for most people than subtraction.

**Steps in figuring rectangular coordinates with Woodworth Tables:**

1. Determine coordinates of "A" and "B" lines (tangent to circle).
2. Multiply "A" factor by diameter of circle.
3. Add result to coordinate of "A" line.
4. Multiply "B" factor by diameter of circle.
5. Add result to coordinate of "B" line.

Fig. 316 — Woodworth Tables eliminate work shown in Fig. 314. Also steps 2, 3, 4, of Fig. 315, which represents about three-quarters of the necessary calculation time, with a proportionate insurance against errors in calculations.

# INSTRUCTIONS FOR USING WOODWORTH CIRCULAR TABLES

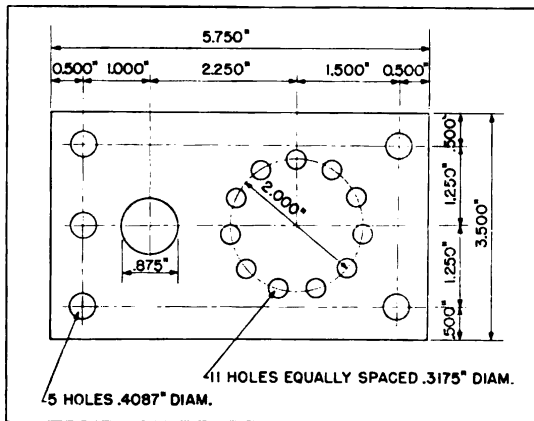


Fig. 317 — Conventionally dimensioned drawing.

It is necessary, of course, to keep the angular orientation of the divided circle in mind. Hole No. 1 must be the first hole counter-clockwise from the vertical center line.

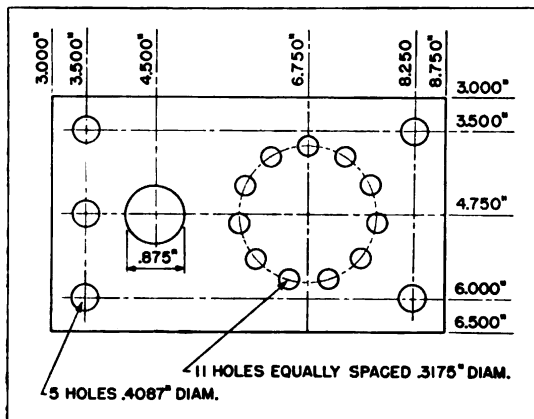


Fig. 318 — Coordinates established for dimensioned holes and center of divided circle.

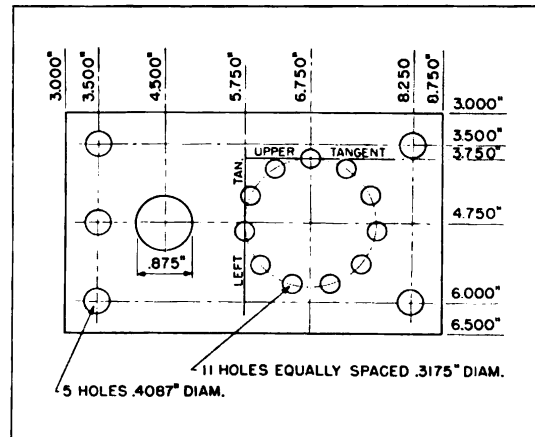


Fig. 319 — Coordinates established for left-hand and upper tangents of divided circle.

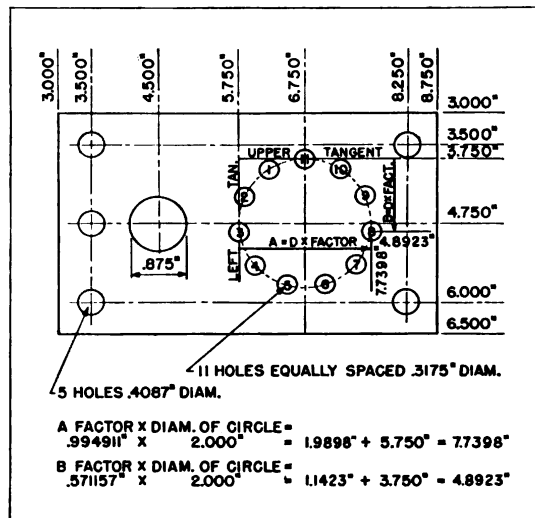
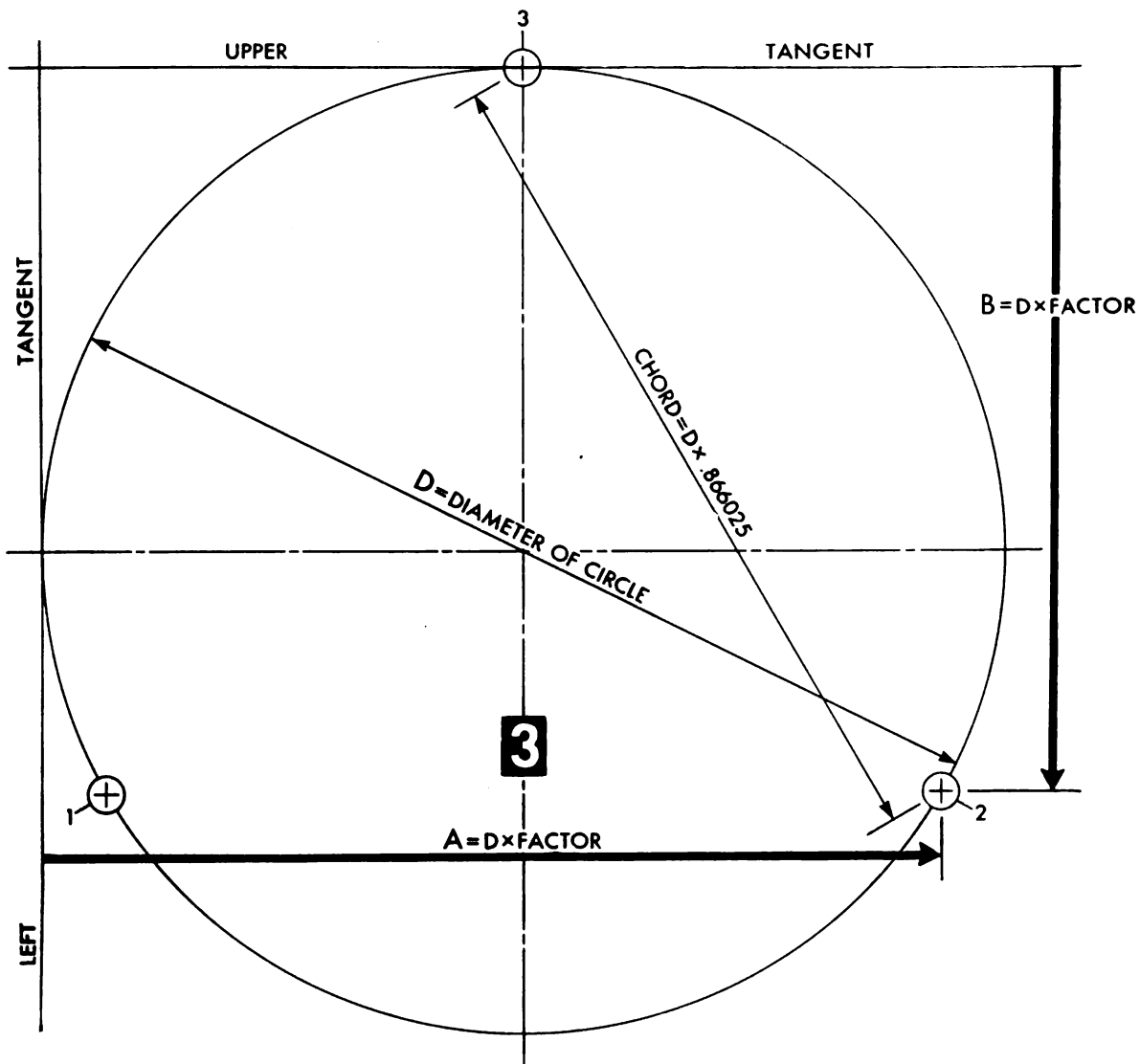


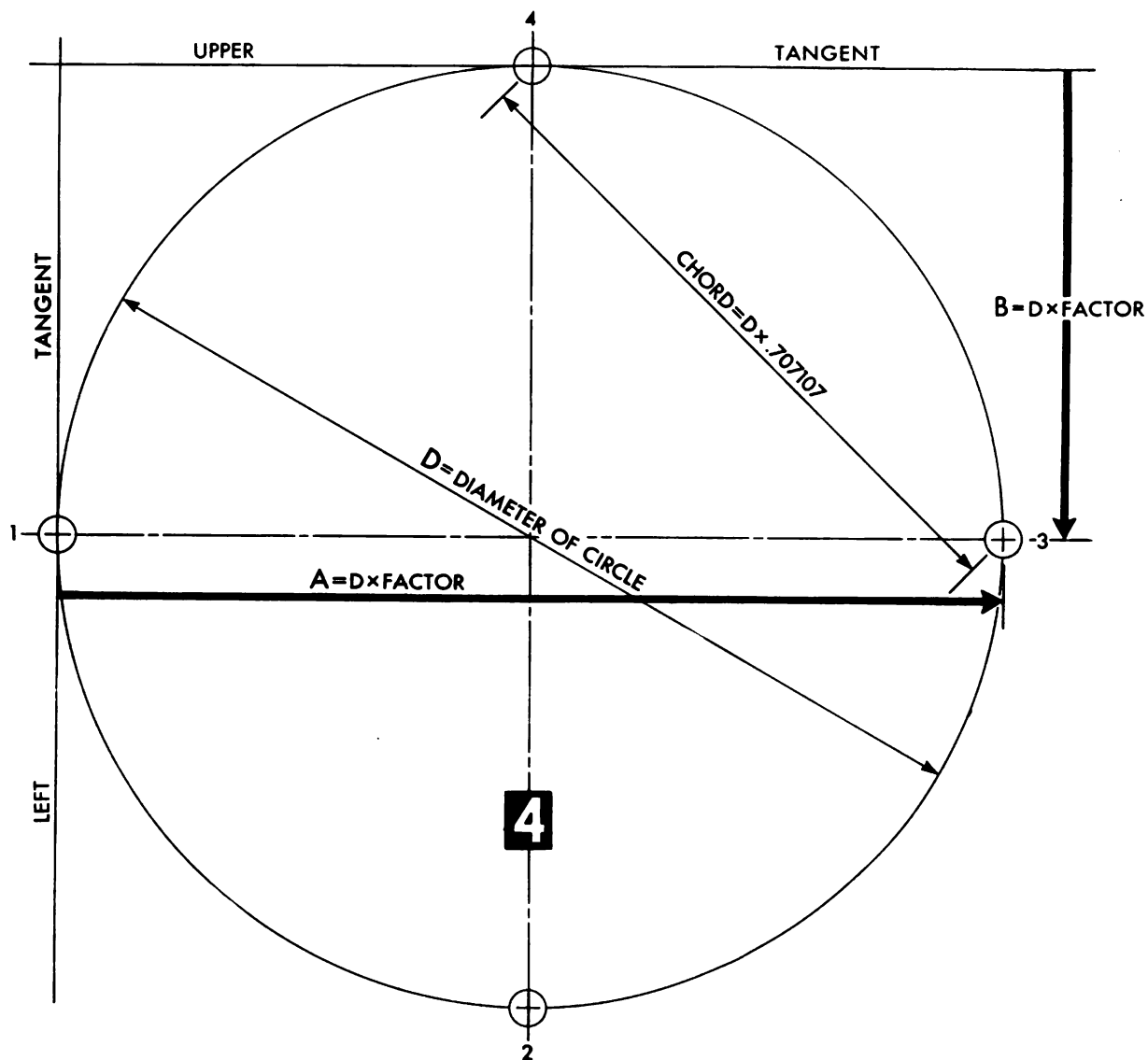
Fig. 320 — The procedure, as here illustrated for hole No. 8, is followed for all remaining holes on the circle.

### 3 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



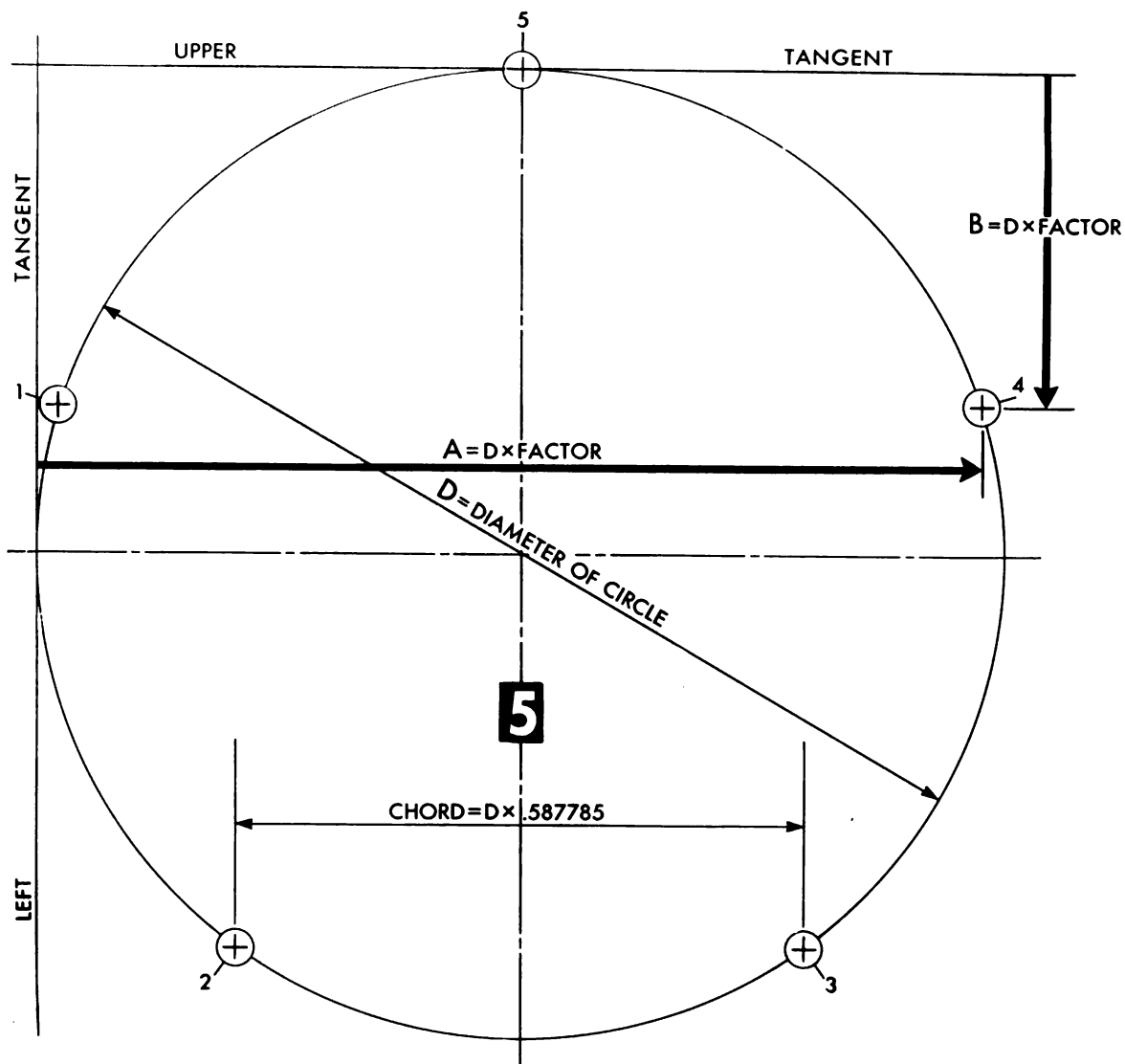
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2		.933013	2	.750000	2	240	0	0
3		.500000	3	.000000	3	360	0	0

# COORDINATE FACTORS AND ANGLES—4 HOLE DIVISION



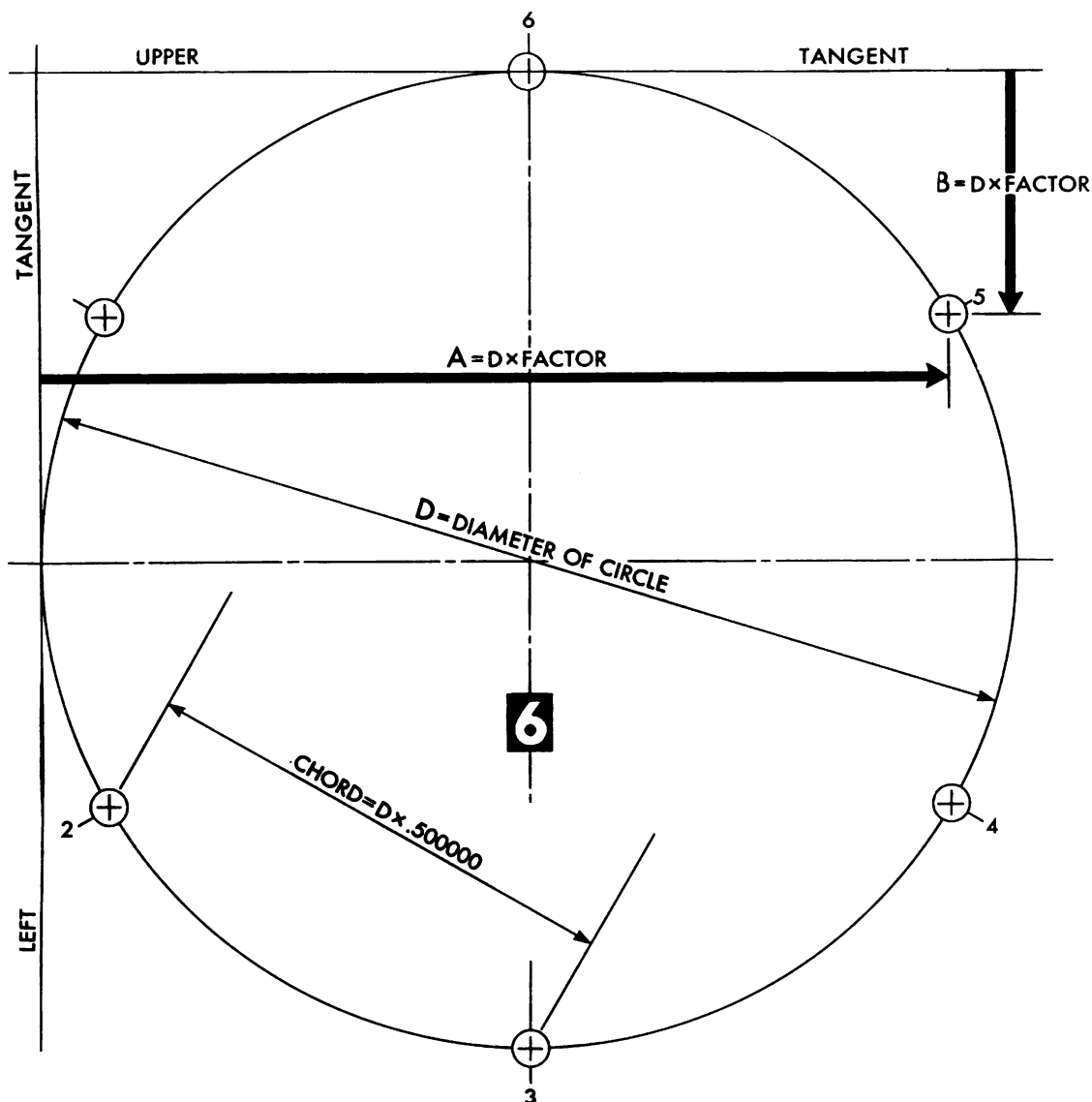
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						DEG.	MIN.	SEC.
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2		.500000	2	1.000000	2	180	0	0
3		1.000000	3	.500000	3	270	0	0
4		.500000	4	.000000	4	360	0	0

# 5 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



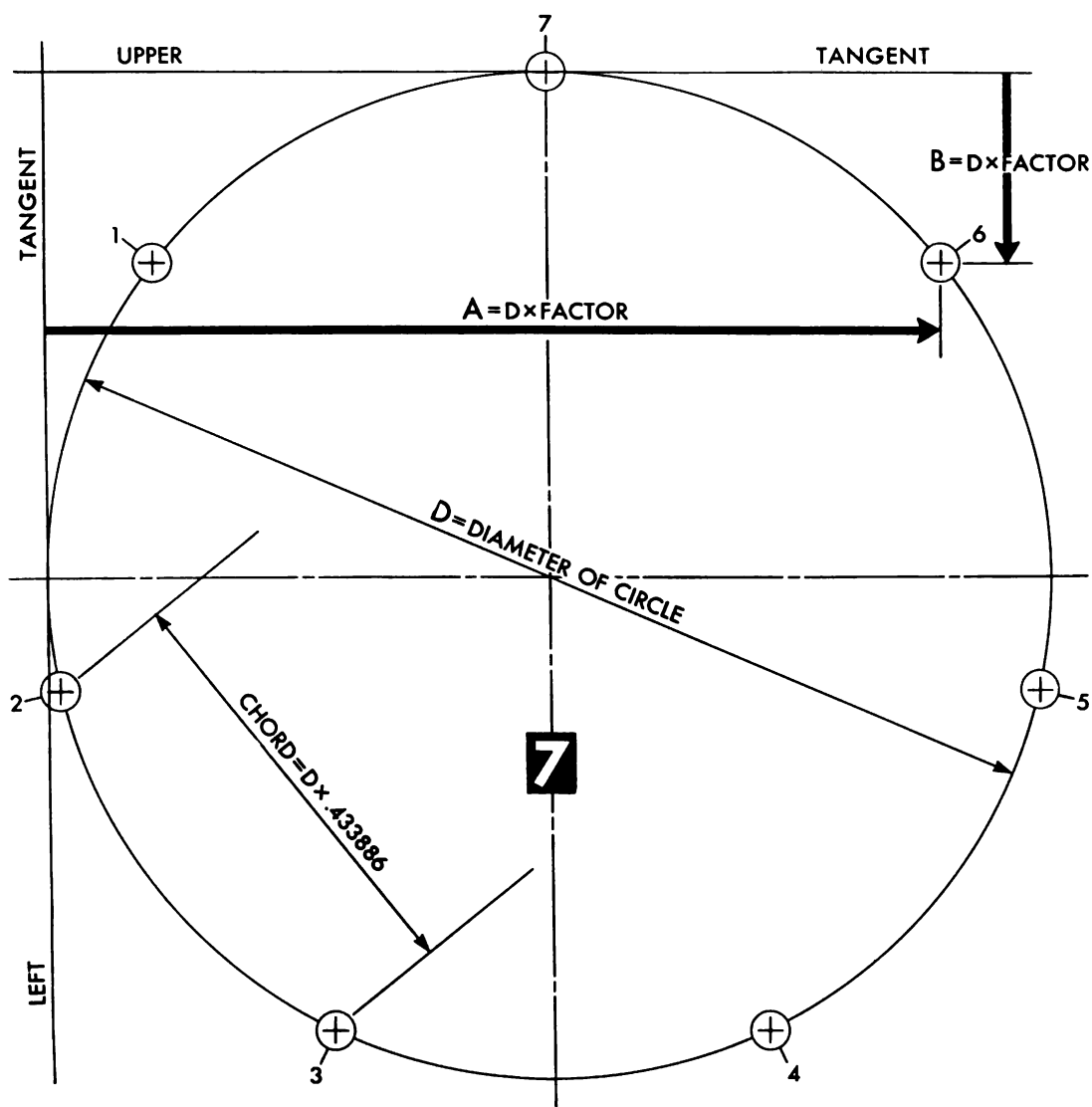
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					DEG.	MIN.	SEC.
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2	.206107	2	.904508	2	144	0	0
3	.793893	3	.904508	3	216	0	0
4	.975528	4	.345492	4	288	0	0
5	.500000	5	.000000	5	360	0	0

# COORDINATE FACTORS AND ANGLES—6 HOLE DIVISION



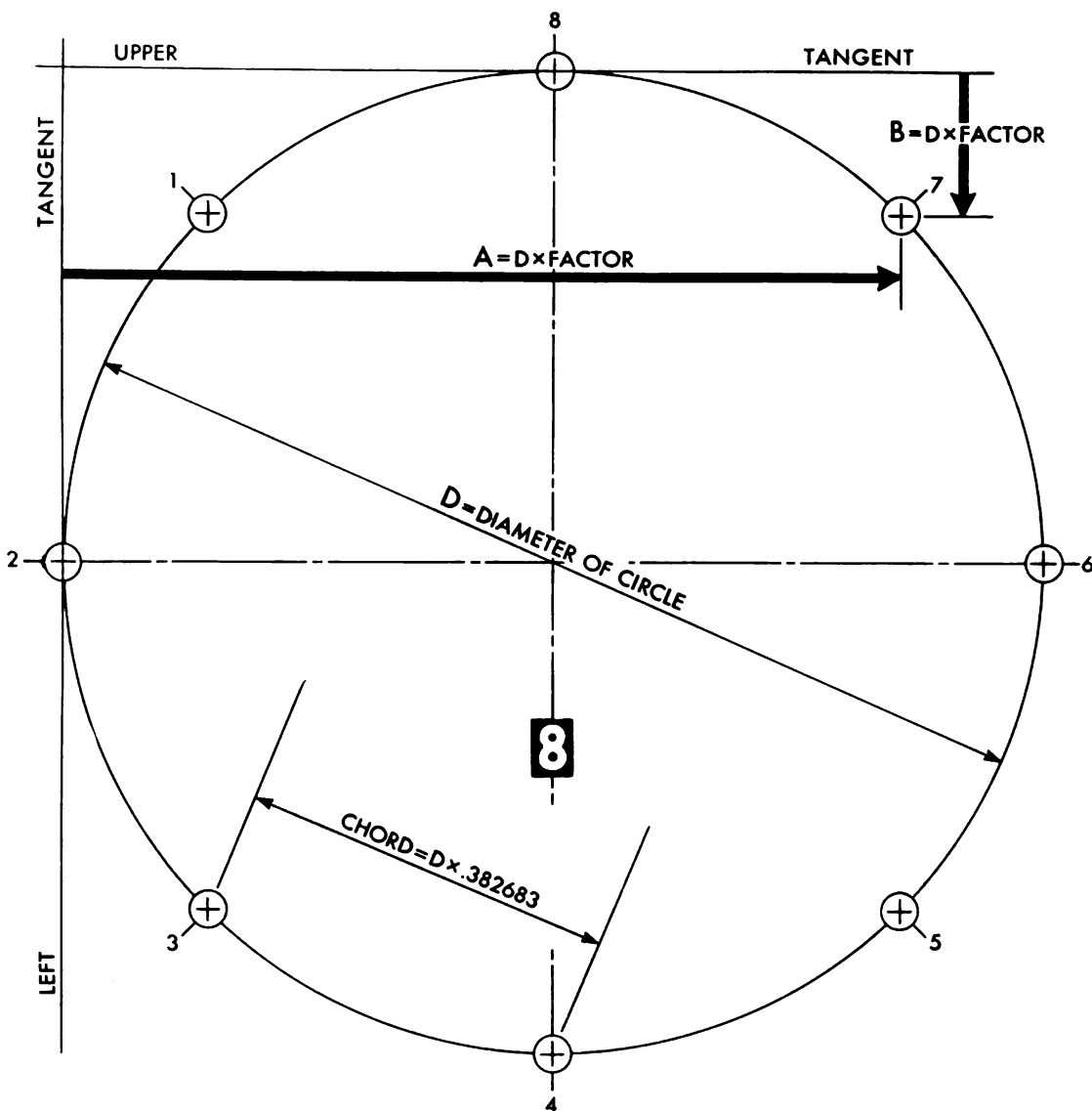
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3		.500000	3	1.000000	3	180	0 0
4		.933013	4	.750000	4	240	0 0
5		.933013	5	.250000	5	300	0 0
6		.500000	6	.000000	6	360	0 0

# 7 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



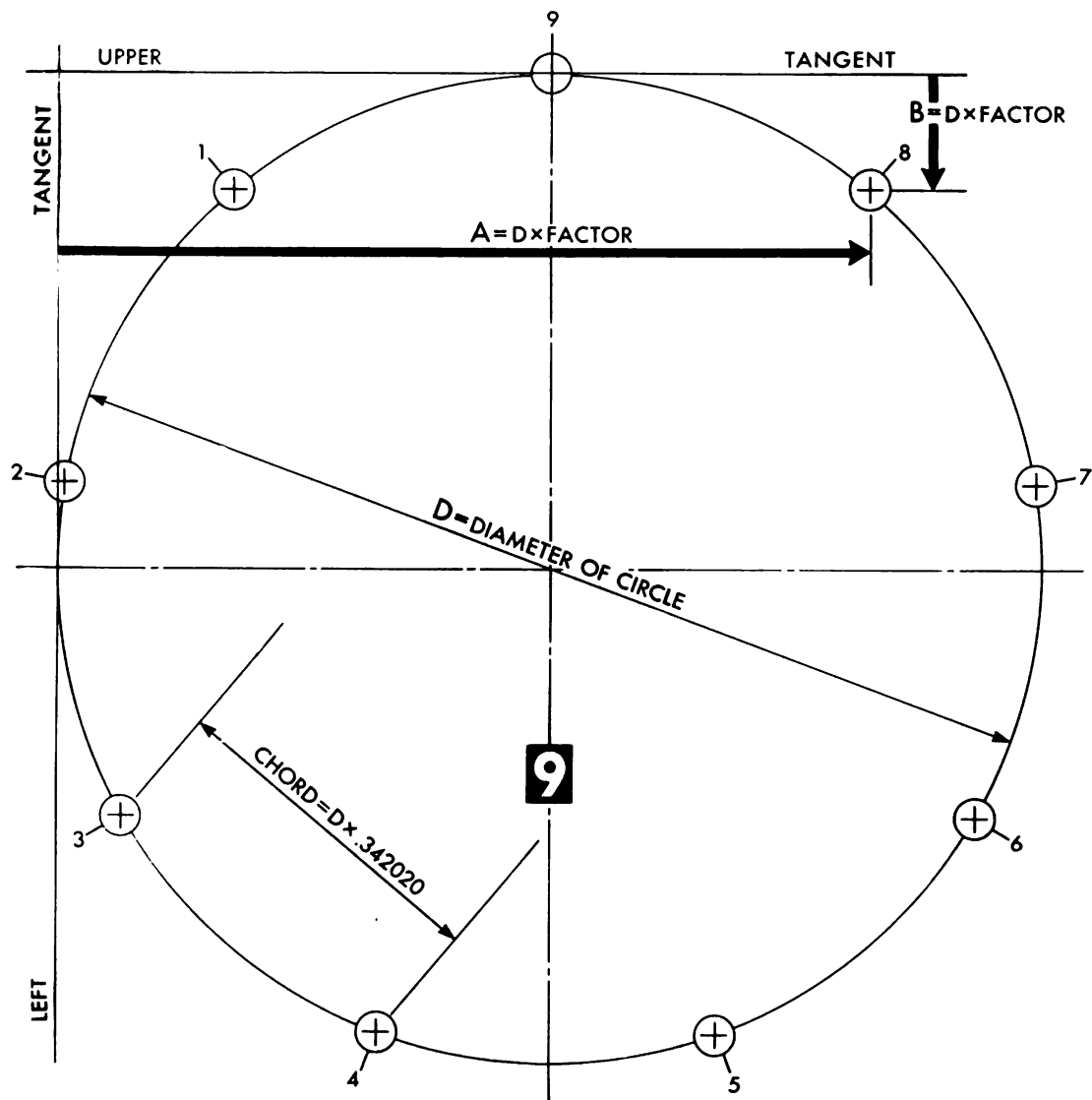
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					DEG.	MIN.	SEC.
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2		.012536	2	.611261	2	102	51 25-5/7
3		.283058	3	.950484	3	154	17 8-4/7
4		.716942	4	.950484	4	205	42 51-3/7
5		.987464	5	.611261	5	257	8 34-2/7
6		.890916	6	.188255	6	308	34 17-1/7
7		.500000	7	.000000	7	360	0 0

# COORDINATE FACTORS AND ANGLES—8 HOLE DIVISION



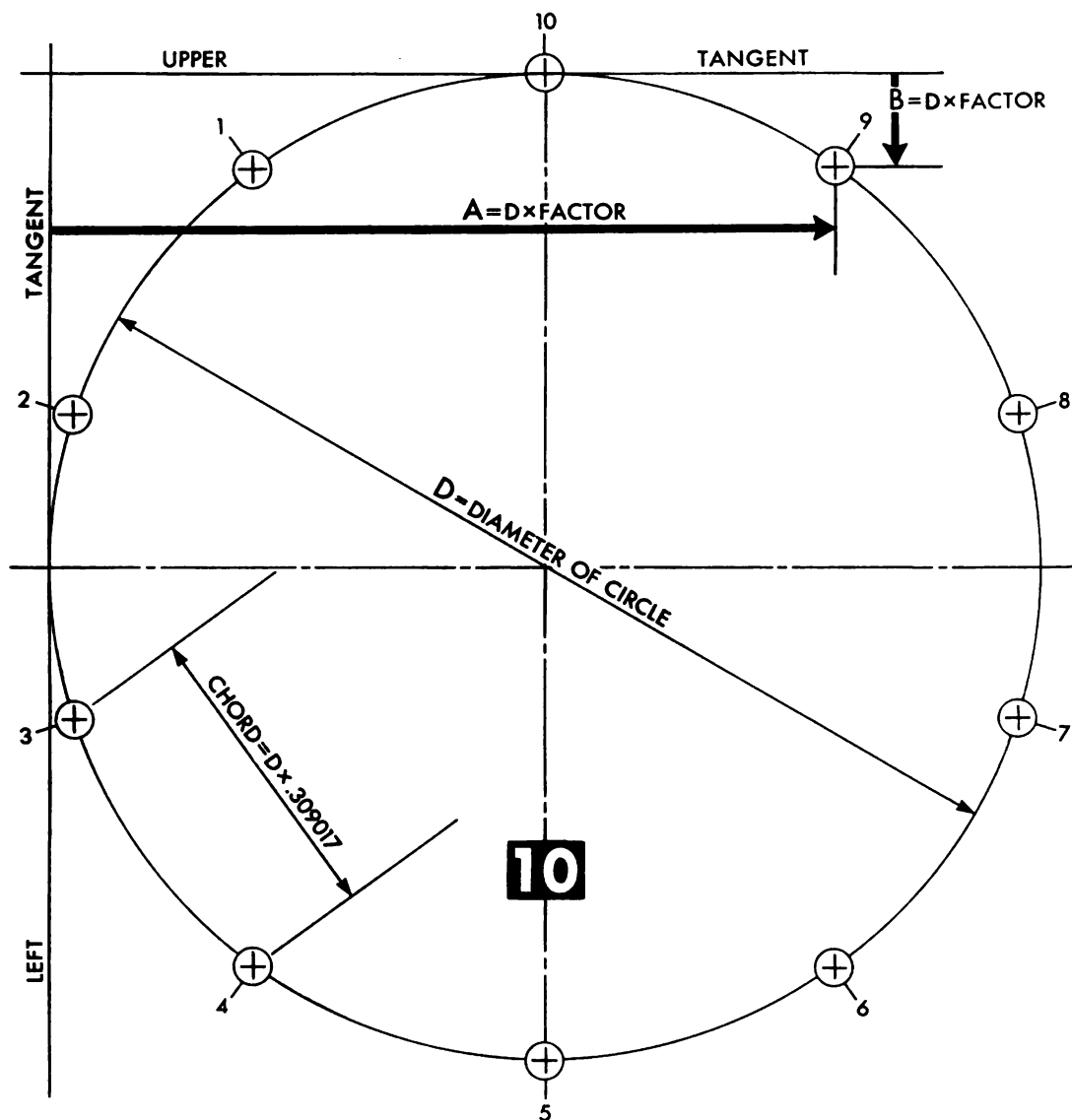
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					DEG.	MIN.	SEC.
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2		.000000	2	.500000	2	90	0 0
3		.146447	3	.853553	3	135	0 0
4		.500000	4	1.000000	4	180	0 0
5		.853553	5	.853553	5	225	0 0
6		1.000000	6	.500000	6	270	0 0
7		.853553	7	.146447	7	315	0 0
8		.500000	8	.000000	8	360	0 0

# 9 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.178606	1	.116978	1	40	0 0
2		.007596	2	.413176	2	80	0 0
3		.066987	3	.750000	3	120	0 0
4		.328990	4	.969846	4	160	0 0
5		.671010	5	.969846	5	200	0 0
6		.933013	6	.750000	6	240	0 0
7		.992404	7	.413176	7	280	0 0
8		.821394	8	.116978	8	320	0 0
9		.500000	9	.000000	9	360	0 0

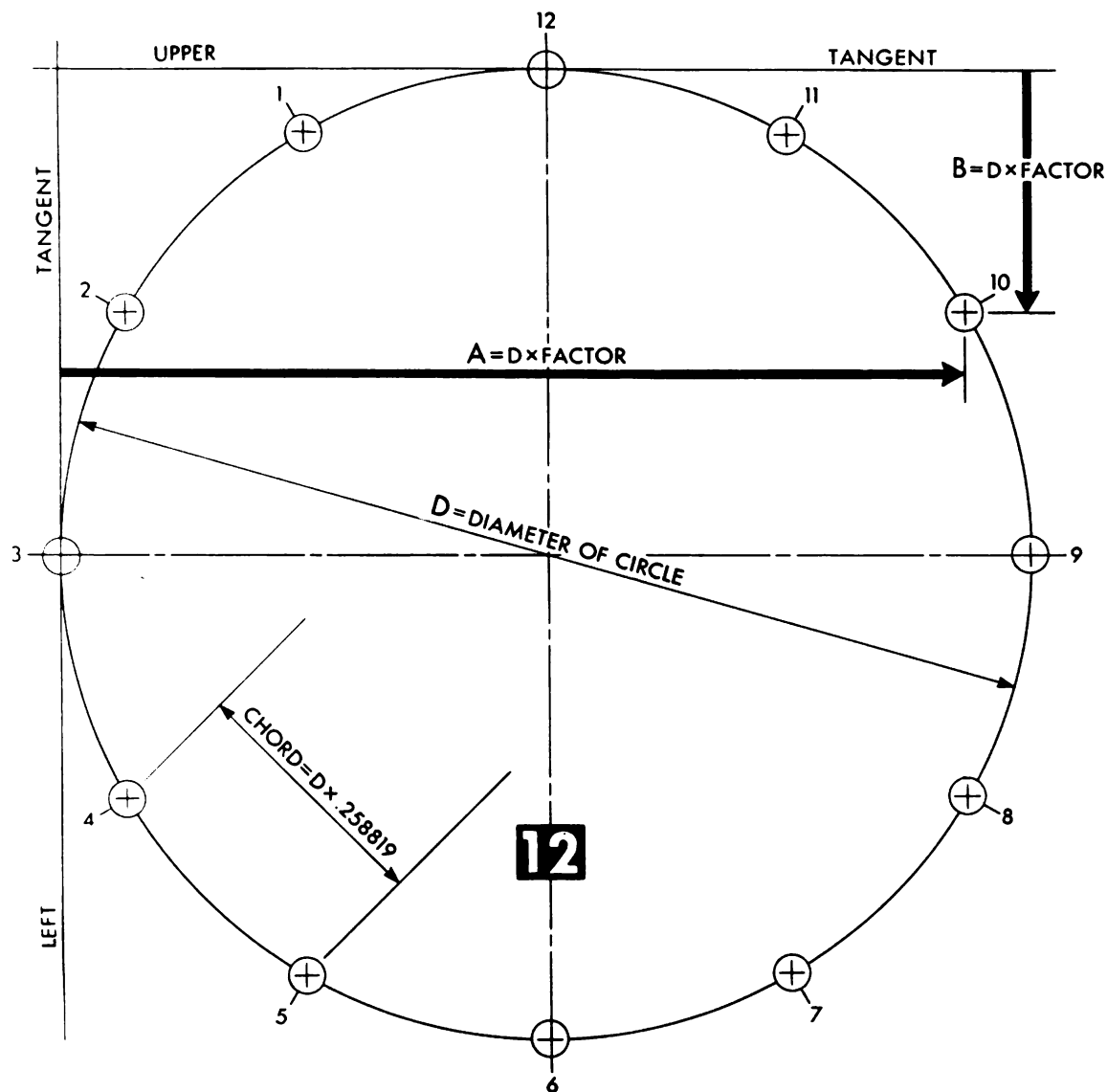
# COORDINATE FACTORS AND ANGLES—10 HOLE DIVISION



	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.206107	1	.095492	1	36	0 0
2		.024472	2	.345492	2	72	0 0
3		.024472	3	.654508	3	108	0 0
4		.206107	4	.904508	4	144	0 0
5		.500000	5	1.000000	5	180	0 0
6		.793893	6	.904508	6	216	0 0
7		.975528	7	.654508	7	252	0 0
8		.975528	8	.345492	8	288	0 0
9		.793893	9	.095492	9	324	0 0
10		.500000	10	.000000	10	360	0 0

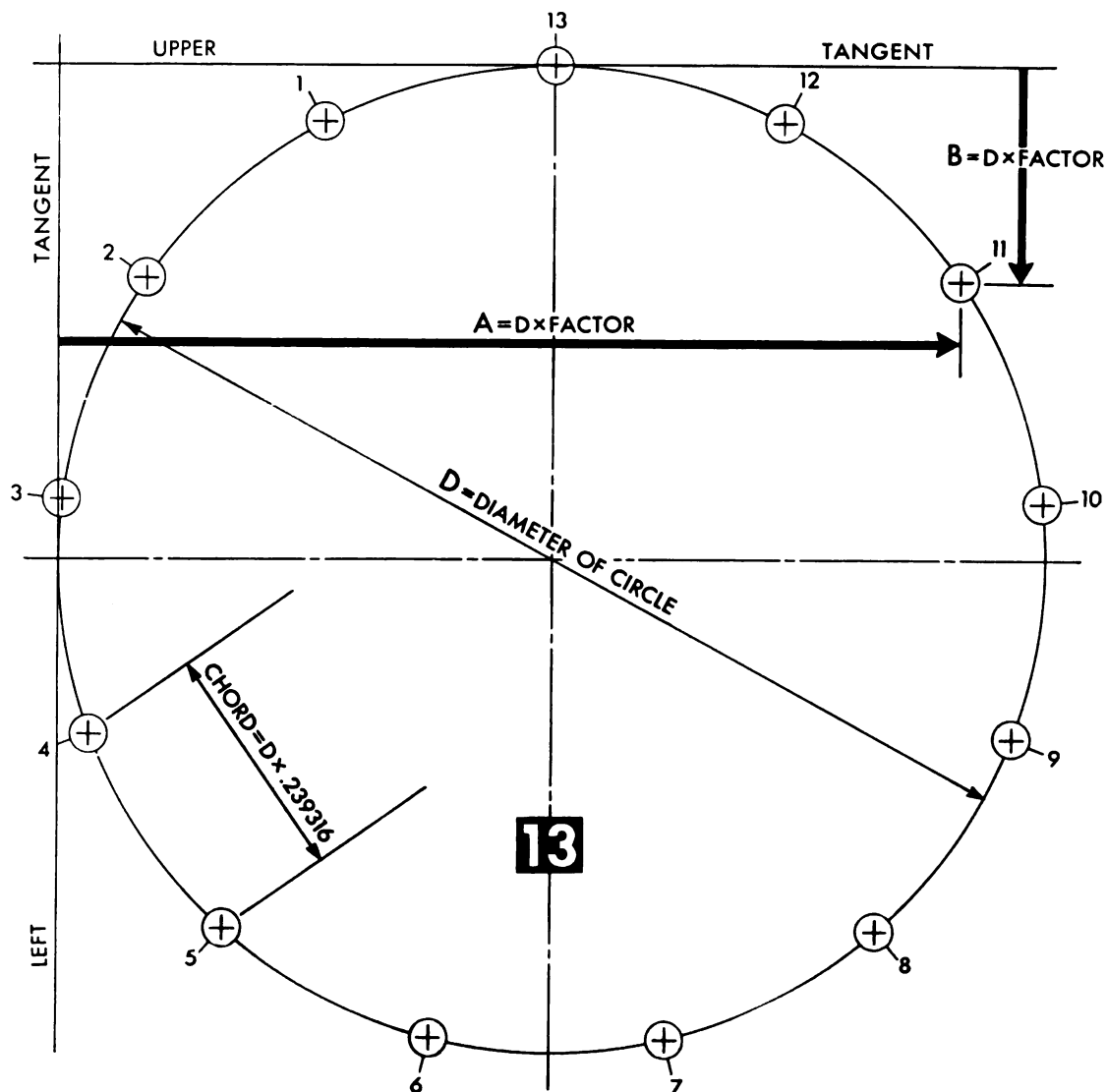
238

# COORDINATE FACTORS AND ANGLES—12 HOLE DIVISION



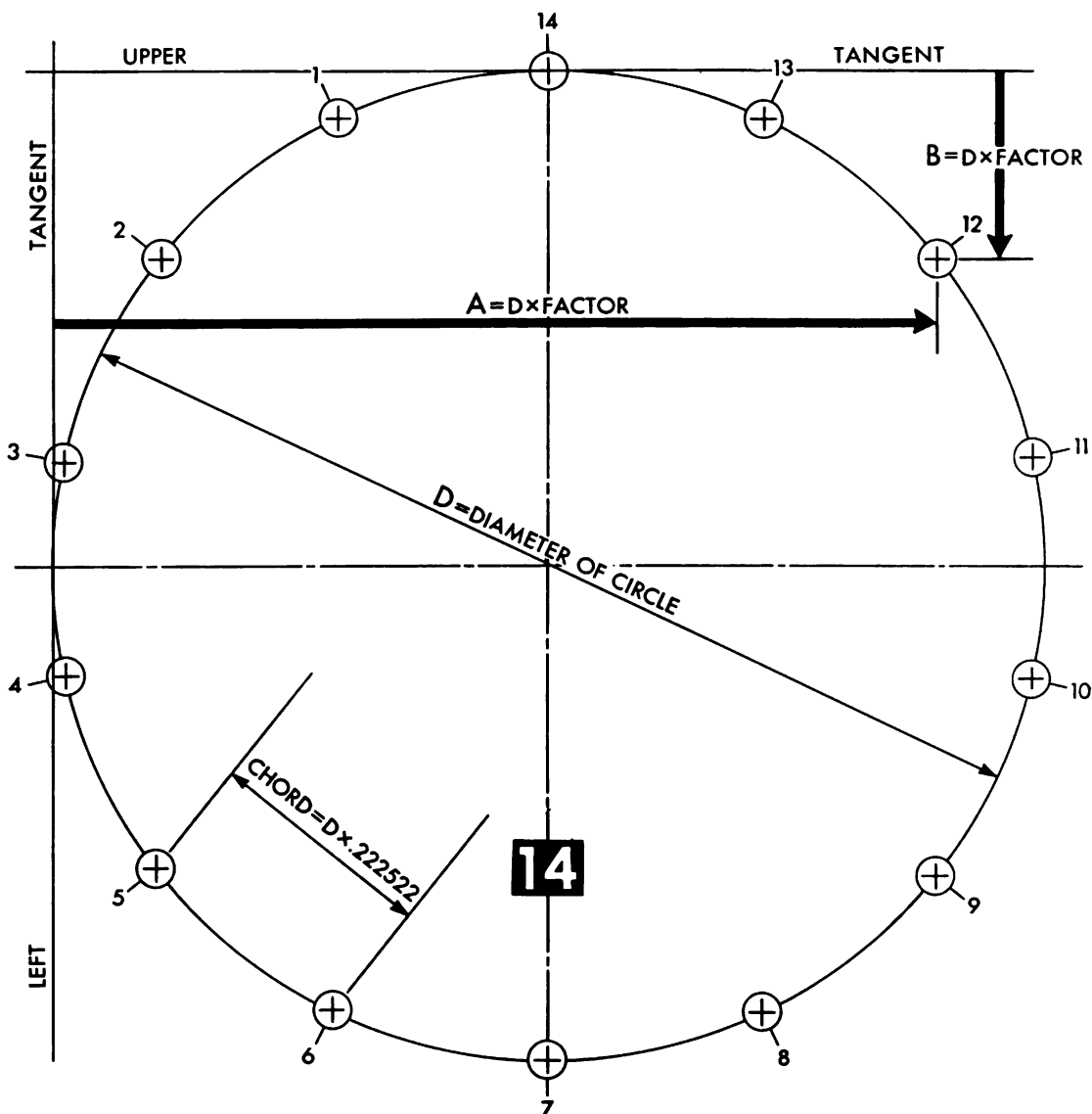
	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.250000	1	.066987	1	30	0 0
2		.066987	2	.250000	2	60	0 0
3		.000000	3	.500000	3	90	0 0
4		.066987	4	.750000	4	120	0 0
5		.250000	5	.933013	5	150	0 0
6		.500000	6	1.000000	6	180	0 0
7		.750000	7	.933013	7	210	0 0
8		.933013	8	.750000	8	240	0 0
9		1.000000	9	.500000	9	270	0 0
10		.933013	10	.250000	10	300	0 0
11		.750000	11	.066987	11	330	0 0
12		.500000	12	.000000	12	360	0 0

# 13 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



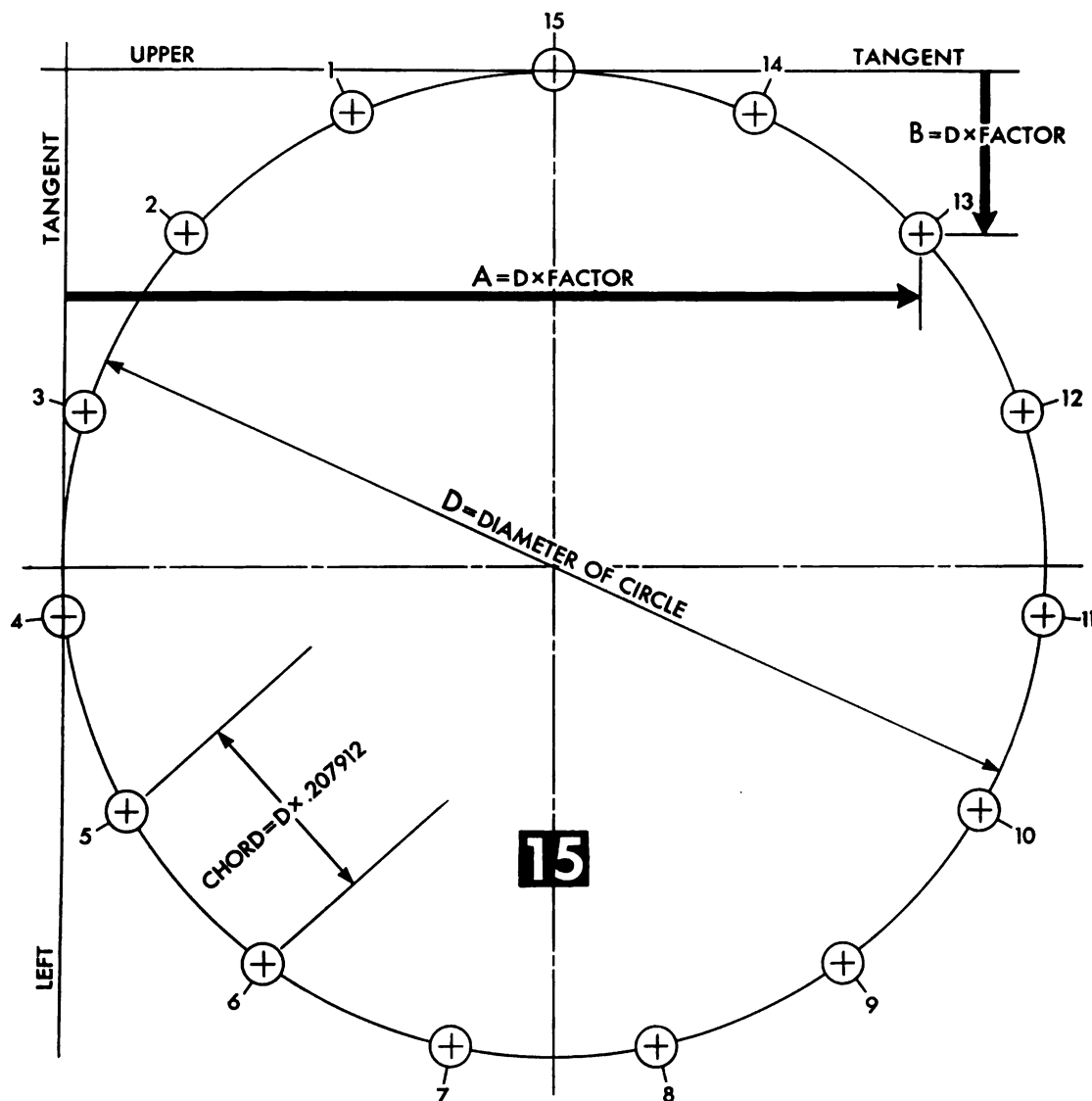
	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
1		.267638	1	.057272	1	27	41	32-	4/13
2		.088508	2	.215968	2	55	23	4-	8/13
3		.003646	3	.439732	3	83	4	36-	12/13
4		.032492	4	.677302	4	110	46	9-	3/13
5		.168439	5	.874255	5	138	27	41-	7/13
6		.380342	6	.985471	6	166	9	13-	11/13
7		.619658	7	.985471	7	193	50	46-	2/13
8		.831561	8	.874255	8	221	32	18-	6/13
9		.967508	9	.677302	9	249	13	50-	10/13
10		.996354	10	.439732	10	276	55	23-	1/13
11		.911492	11	.215968	11	304	36	55-	5/13
12		.732362	12	.057272	12	332	18	27-	9/13
13		.500000	13	.000000	13	360	0	0	

# COORDINATE FACTORS AND ANGLES—14 HOLE DIVISION



	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.283058	1	.049516	1	25	42	51- 6/14
2	.109084	2	.188255	2	51	25	42-12/14
3	.012536	3	.388740	3	77	8	34- 4/14
4	.012536	4	.611261	4	102	51	25-10/14
5	.109084	5	.811745	5	128	34	17- 2/14
6	.283058	6	.950484	6	154	17	8- 8/14
7	.500000	7	1.000000	7	180	00	00000000
8	.716942	8	.950484	8	205	42	51- 6/14
9	.890916	9	.811745	9	231	25	42-12/14
10	.987464	10	.611261	10	257	8	34- 4/14
11	.987464	11	.388740	11	282	51	25-10/14
12	.890916	12	.188255	12	308	34	17- 2/14
13	.716942	13	.049516	13	334	17	8- 8/14
14	.500000	14	.000000	14	360	0	0

# 15 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

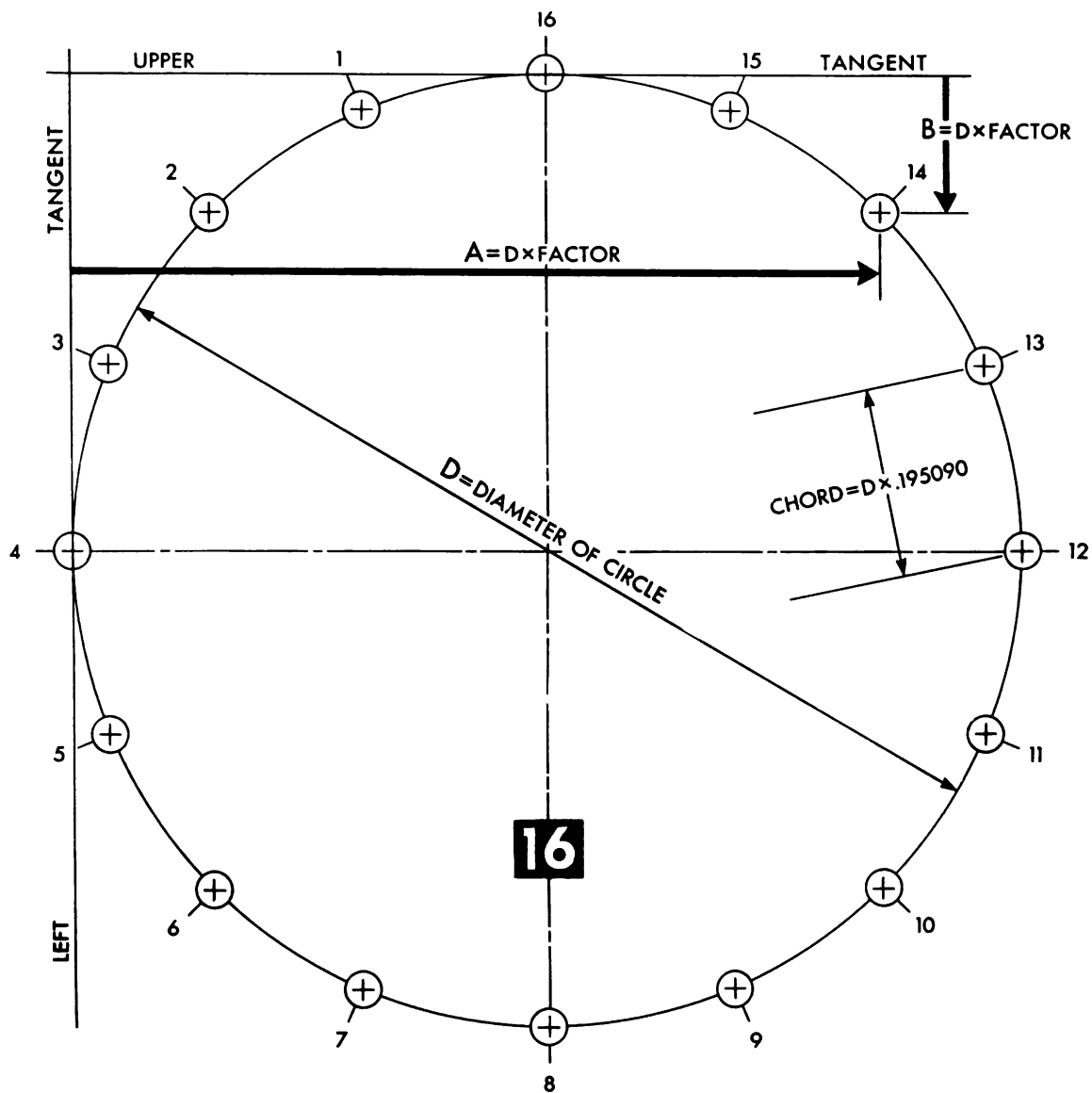


	FACTOR FOR "A"	FACTOR FOR "B"		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.296632	1	.043227	1	24	0 0
2	.128428	2	.165435	2	48	0 0
3	.024472	3	.345492	3	72	0 0
4	.002739	4	.552264	4	96	0 0
5	.066987	5	.750000	5	120	0 0
6	.206107	6	.904509	6	144	0 0
7	.396044	7	.989074	7	168	0 0
8	.603956	8	.989074	8	192	0 0
9	.793893	9	.904509	9	216	0 0
10	.933013	10	.750000	10	240	0 0

# COORDINATE FACTORS AND ANGLES—15 HOLE DIVISION

	➡	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
11		.997261	11	.552264	11	264	0	0
12		.975528	12	.345492	12	288	0	0
13		.871572	13	.165435	13	312	0	0
14		.703368	14	.043227	14	336	0	0
15		.500000	15	.000000	15	360	0	0

# 16 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

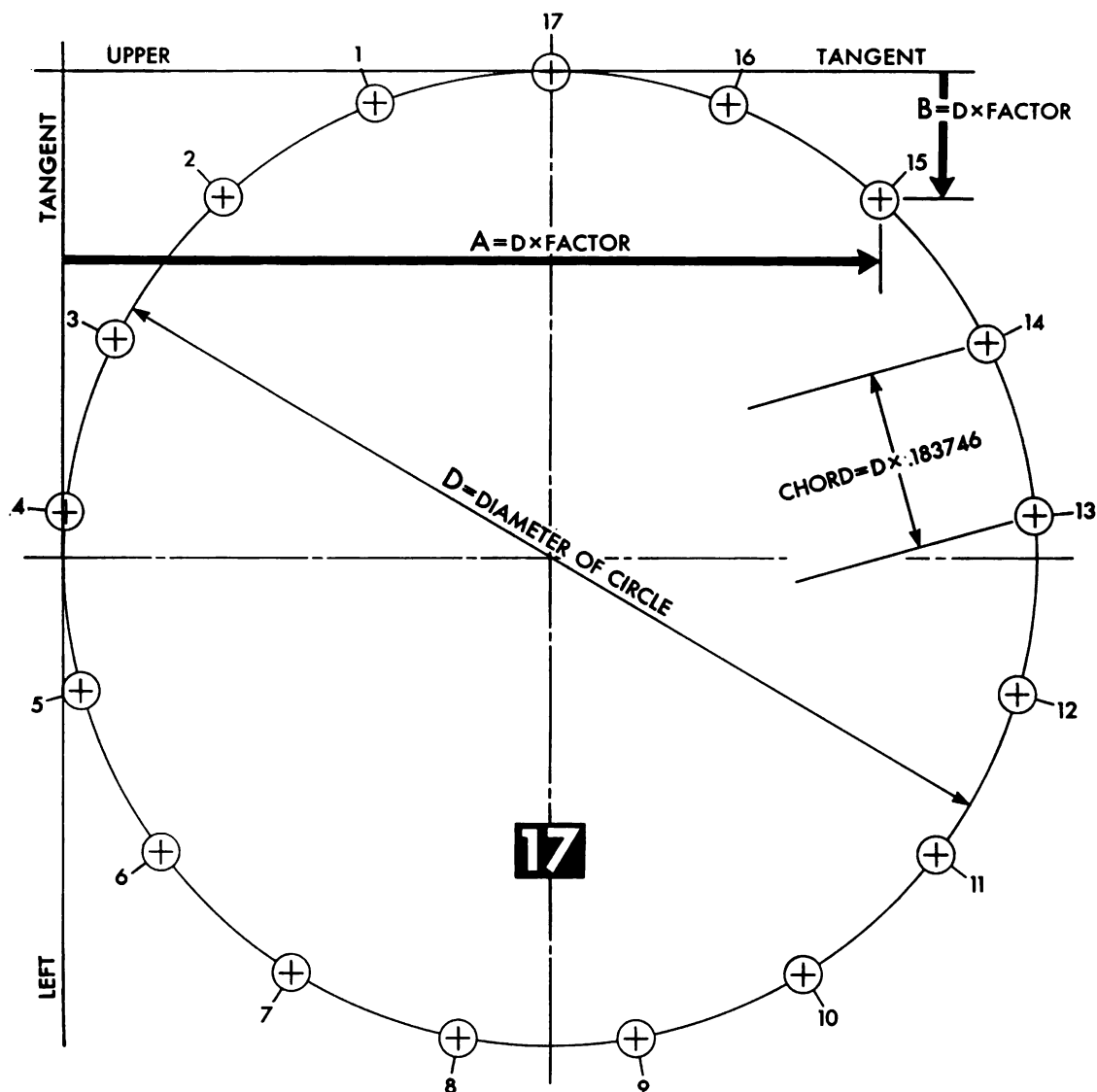


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.308658	1	.038060	1	22	30	0
2		.146447	2	.146447	2	45	00	0
3		.038060	3	.308658	3	67	30	0
4		.000000	4	.500000	4	90	00	0
5		.038060	5	.691342	5	112	30	0
6		.146447	6	.853553	6	135	00	0
7		.308658	7	.961940	7	157	30	0
8		.500000	8	1.000000	8	180	00	0
9		.691342	9	.961940	9	202	30	0
10		.853553	10	.853553	10	225	00	0

# **COORDINATE FACTORS AND ANGLES—16 HOLE DIVISION**

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
11	.961940	11	.691342	11	247	30	0	
12	1.000000	12	.500000	12	270	00	0	
13	.961940	13	.308658	13	292	30	0	
14	.853553	14	.146447	14	315	00	0	
15	.691342	15	.038060	15	337	30	0	
16	.500000	16	.000000	16	360	0	0	

# 17 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

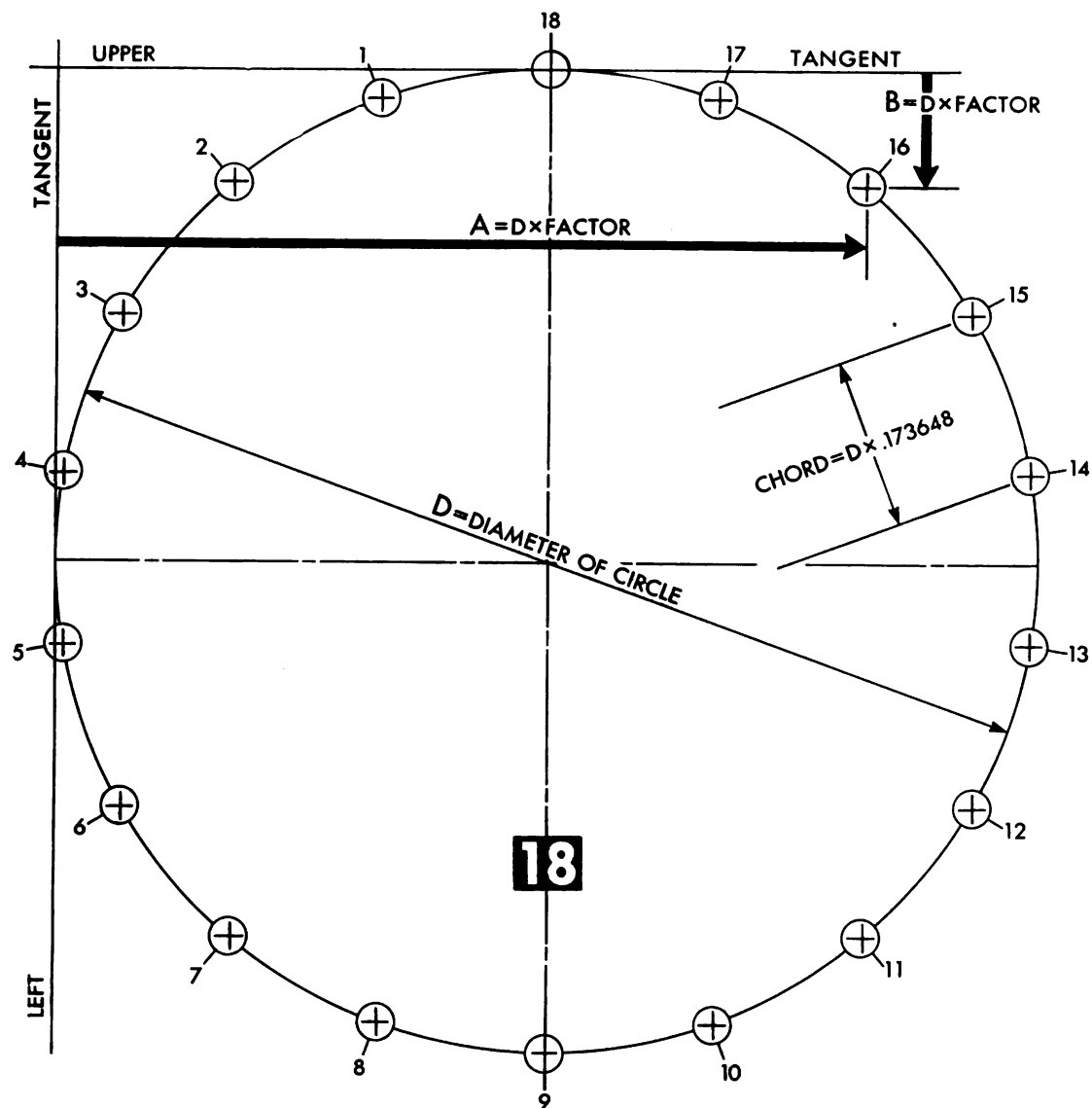


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.319379	1	.033764	1	21	10 35- 5/17
2		.163152	2	.130496	2	42	21 10-10/17
3		.052418	3	.277131	3	63	31 45-15/17
4		.002133	4	.453866	4	84	42 21- 3/17
5		.019087	5	.636832	5	105	52 56- 8/17
6		.100991	6	.801317	6	127	3 31-13/17
7		.236784	7	.925109	7	148	14 7- 1/17
8		.408125	8	.991487	8	169	24 42- 6/17
9		.591875	9	.991487	9	190	35 17-11/17
10		.763216	10	.925109	10	211	45 52-16/17

# COORDINATE FACTORS AND ANGLES—17 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.899009	11	.801317	11	232	56 28- 4/17
12		.980913	12	.636832	12	254	7 3- 9/17
13		.997867	13	.453866	13	275	17 38-14/17
14		.947582	14	.277131	14	296	28 14- 2/17
15		.836848	15	.130496	15	317	38 49- 7/17
16		.680621	16	.033764	16	338	49 24-12/17
17		.500000	17	.000000	17	360	0 0

# 18 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.328990	1	.030154	1	20	0 0
2	.178606	2	.116978	2	40	0 0
3	.066987	3	.250000	3	60	0 0
4	.007596	4	.413176	4	80	0 0
5	.007596	5	.586824	5	100	0 0
6	.066987	6	.750000	6	120	0 0
7	.178606	7	.883022	7	140	0 0
8	.328990	8	.969846	8	160	0 0
9	.500000	9	1.000000	9	180	0 0
10	.671010	10	.969846	10	200	0 0

# COORDINATE FACTORS AND ANGLES—18 HOLE DIVISION

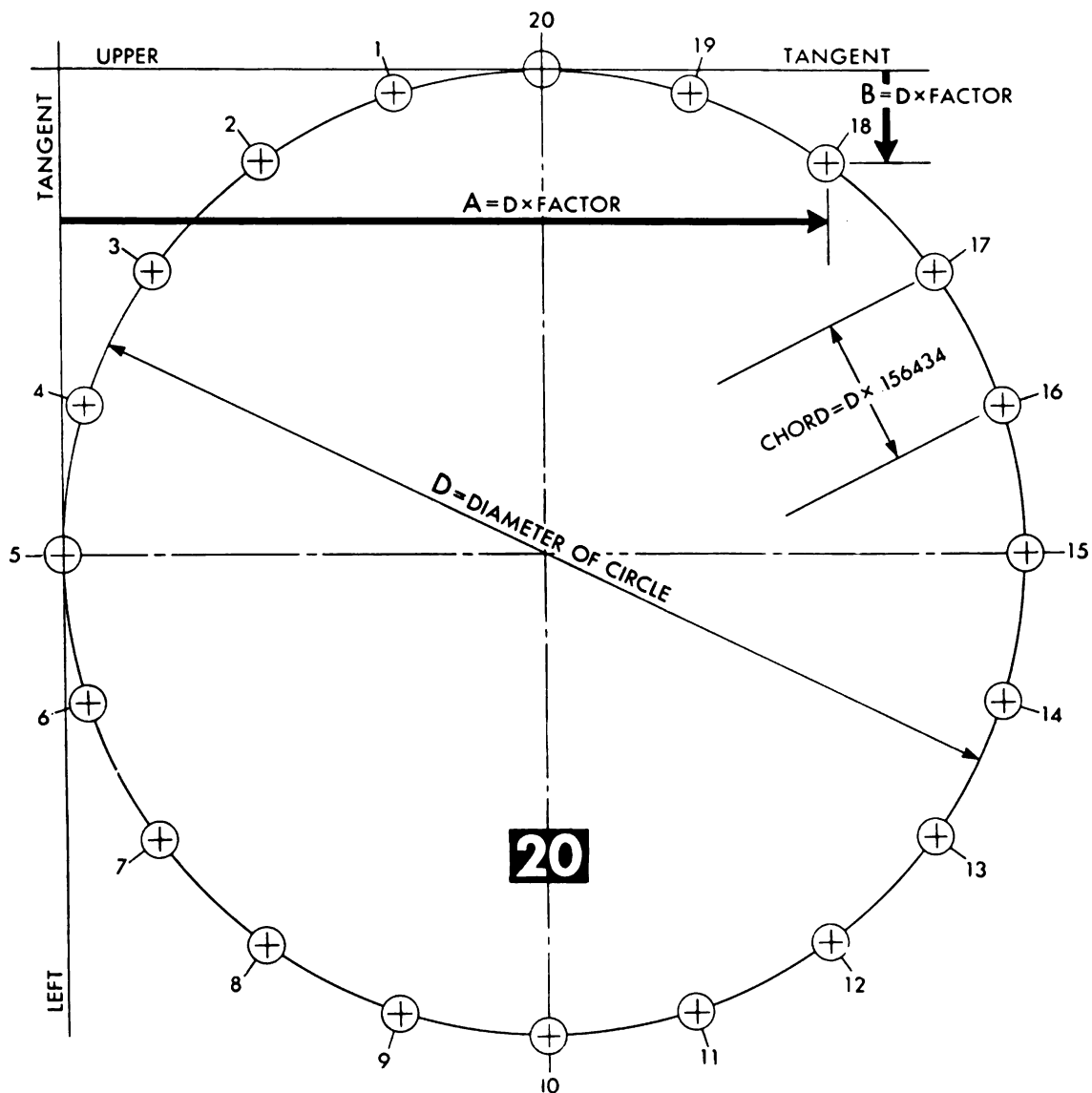
	→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
11		.821394	11	.883022	11	220	0	0
12		.933013	12	.750000	12	240	0	0
13		.992404	13	.586824	13	260	0	0
14		.992404	14	.413176	14	280	0	0
15		.933013	15	.250000	15	300	0	0
16		.821394	16	.116978	16	320	0	0
17		.671010	17	.030154	17	340	0	0
18		.500000	18	.000000	18	360	0	0

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# COORDINATE FACTORS AND ANGLES—19 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.737974	11	.939737	11	208	25 15-15/19
12		.867862	12	.838641	12	227	22 6- 6/19
13		.957887	13	.700848	13	246	18 56-16/19
14		.998292	14	.541290	14	265	15 47- 7/19
15		.984700	15	.377257	15	284	12 37-17/19
16		.918583	16	.226526	16	303	9 28- 8/19
17		.807106	17	.105430	17	322	6 18-18/19
18		.662350	18	.027091	18	341	3 9- 9/19
19		.500000	19	.000000	19	360	0 0

## 20 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

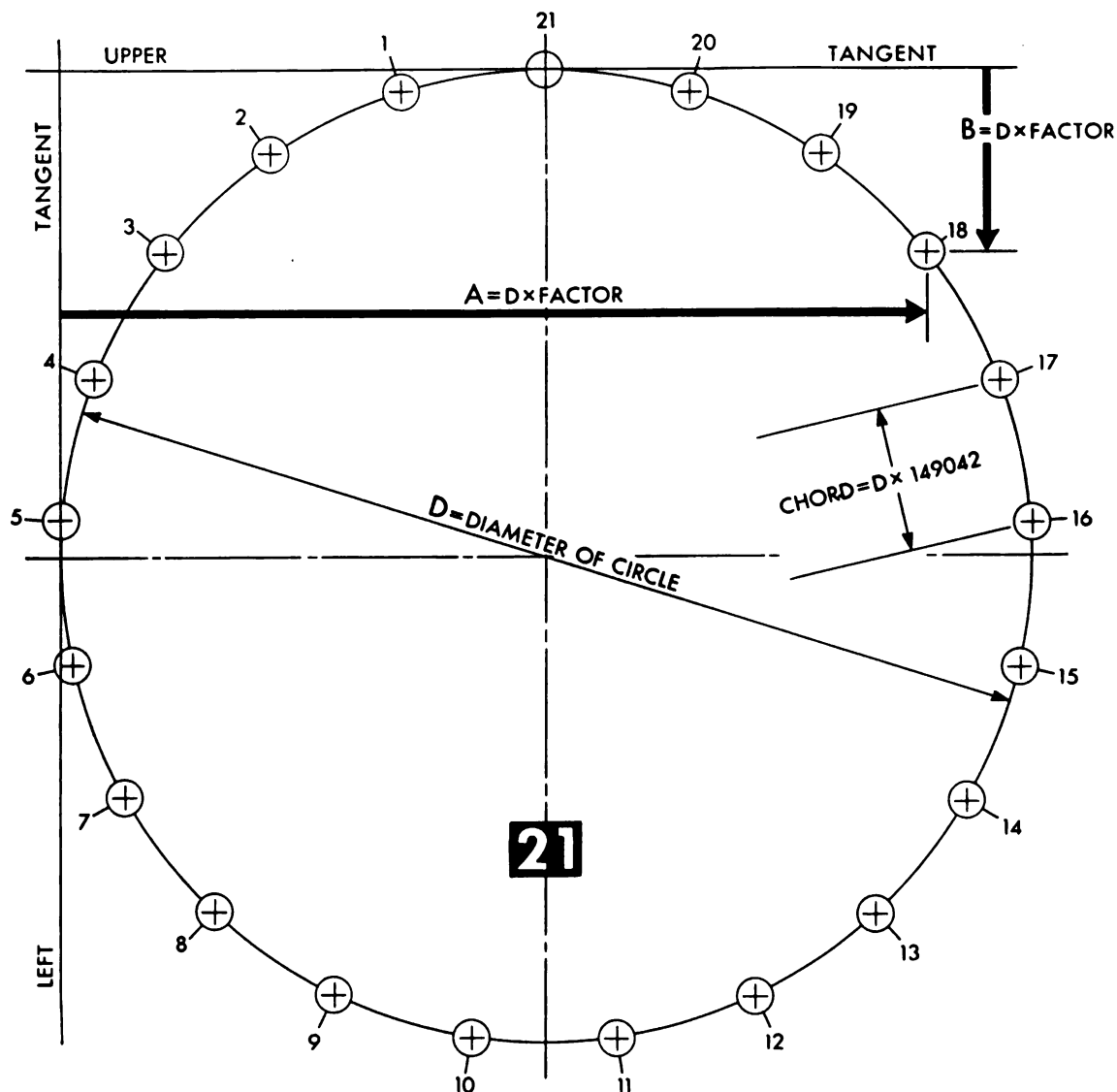


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.345492	1	.024472	1	18	0	0
2		.206107	2	.095492	2	36	0	0
3		.095492	3	.206107	3	54	0	0
4		.024472	4	.345492	4	72	0	0
5		.000000	5	.500000	5	90	0	0
6		.024472	6	.654508	6	108	0	0
7		.095492	7	.793893	7	126	0	0
8		.206107	8	.904508	8	144	0	0
9		.345492	9	.975528	9	162	0	0
10		.500000	10	1.000000	10	180	0	0

# COORDINATE FACTORS AND ANGLES—20 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.654508	11	.975528	11	198	0	0
12	.793893	12	.904508	12	216	0	0
13	.904508	13	.793893	13	234	0	0
14	.975528	14	.654508	14	252	0	0
15	1.000000	15	.500000	15	270	0	0
16	.975528	16	.345492	16	288	0	0
17	.904508	17	.206107	17	306	0	0
18	.793893	18	.095492	18	324	0	0
19	.654508	19	.024472	19	342	0	0
20	.500000	20	.000000	20	360	0	0

## 21 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

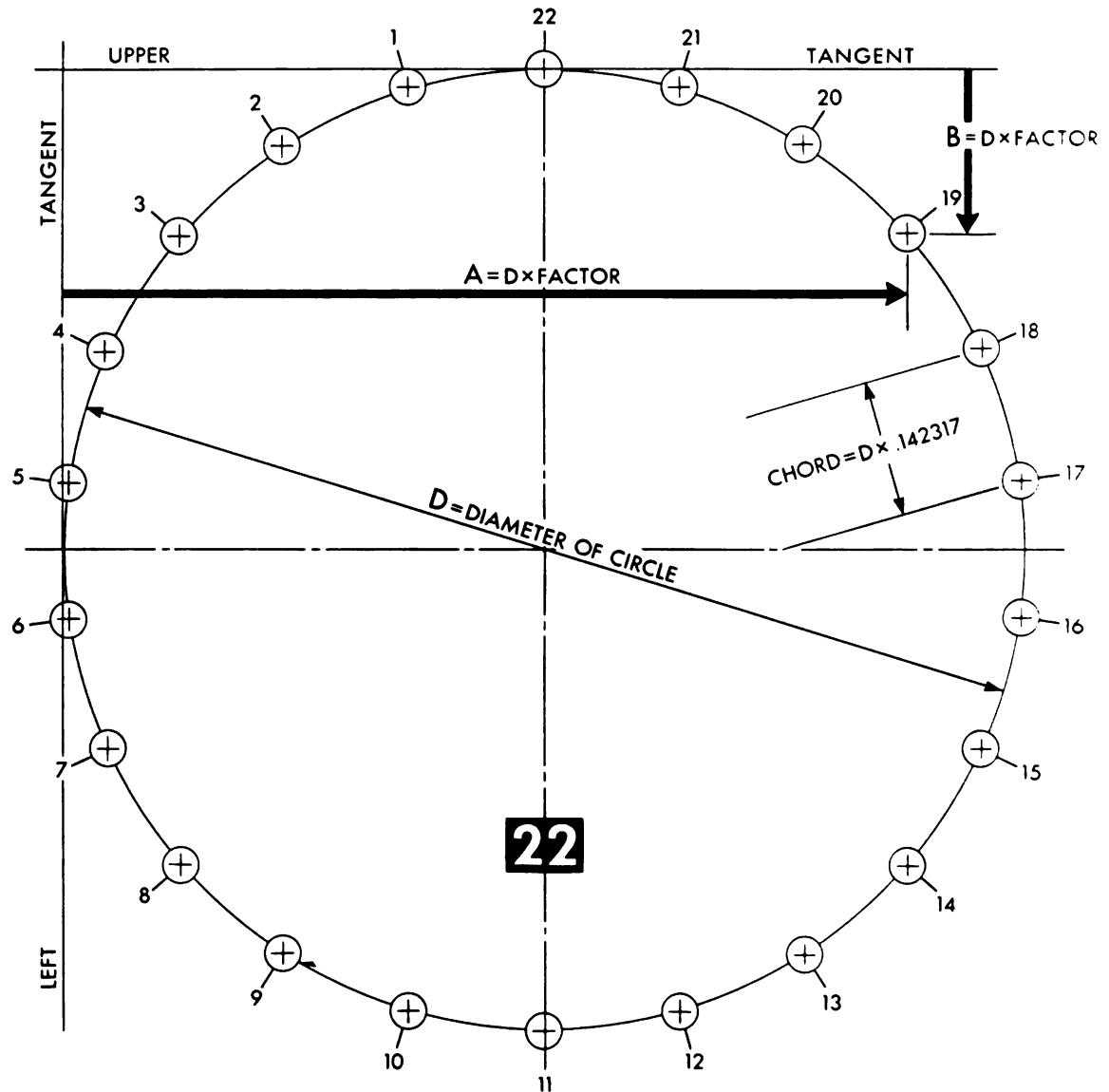


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.352622	1	.022214	1	17	8 34- 6/21
2		.218340	2	.086881	2	34	17 8-12/21
3		.109084	3	.188255	3	51	25 42-18/21
4		.034563	4	.317329	4	68	34 17- 3/21
5		.001398	5	.462635	5	85	42 51- 9/21
6		.012536	6	.611260	6	102	51 25-15/21
7		.066987	7	.750000	7	120	00 00000000
8		.159914	8	.866526	8	137	8 34- 6/21
9		.283058	9	.950484	9	154	17 8-12/21
10		.425479	10	.994415	10	171	25 42-18/21

# COORDINATE FACTORS AND ANGLES—21 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.574521	11	.994415	11	188	34 17- 3/21
12		.716942	12	.950484	12	205	42 51- 9/21
13		.840086	13	.866526	13	222	51 25-15/21
14		.933013	14	.750000	14	240	00 00000000
15		.987464	15	.611260	15	257	8 34- 6/21
16		.998602	16	.462635	16	274	17 8-12/21
17		.965437	17	.317329	17	291	25 42-18/21
18		.890916	18	.188255	18	308	34 17- 3/21
19		.781660	19	.086881	19	325	42 51- 9/21
20		.647378	20	.022214	20	342	51 25-15/21
21		.500000	21	.000000	21	360	0 0

## 22 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.359134	1	.020254	1	16	21 49- 2/22
2		.229680	2	.079373	2	32	43 38- 4/22
3		.122125	3	.172570	3	49	5 27- 6/22
4		.045184	4	.292293	4	65	27 16- 8/22
5		.005089	5	.428843	5	81	49 5-10/22
6		.005089	6	.571157	6	98	10 54-12/22
7		.045184	7	.707708	7	114	32 43-14/22
8		.122125	8	.827430	8	130	54 32-16/22
9		.229680	9	.920627	9	147	16 21-18/22
10		.359134	10	.979746	10	163	38 10-20/22

# COORDINATE FACTORS AND ANGLES—22 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.500000	11	1.000000	11	180	00 00000000
12		.640866	12	.979746	12	196	21 49- 2/22
13		.770320	13	.920627	13	212	43 38- 4/22
14		.877875	14	.827430	14	229	5 27- 6/22
15		.954816	15	.707708	15	245	27 16- 8/22
16		.994911	16	.571157	16	261	49 5-10/22
17		.994911	17	.428843	17	278	10 54-12/22
18		.954816	18	.292293	18	294	32 43-14/22
19		.877875	19	.172570	19	310	54 32-16/22
20		.770320	20	.079373	20	327	16 21-18/22
21		.640866	21	.020254	21	343	38 10-20/22
22		.500000	22	.000000	22	360	0 0

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# COORDINATE FACTORS AND ANGLES—23 HOLE DIVISION

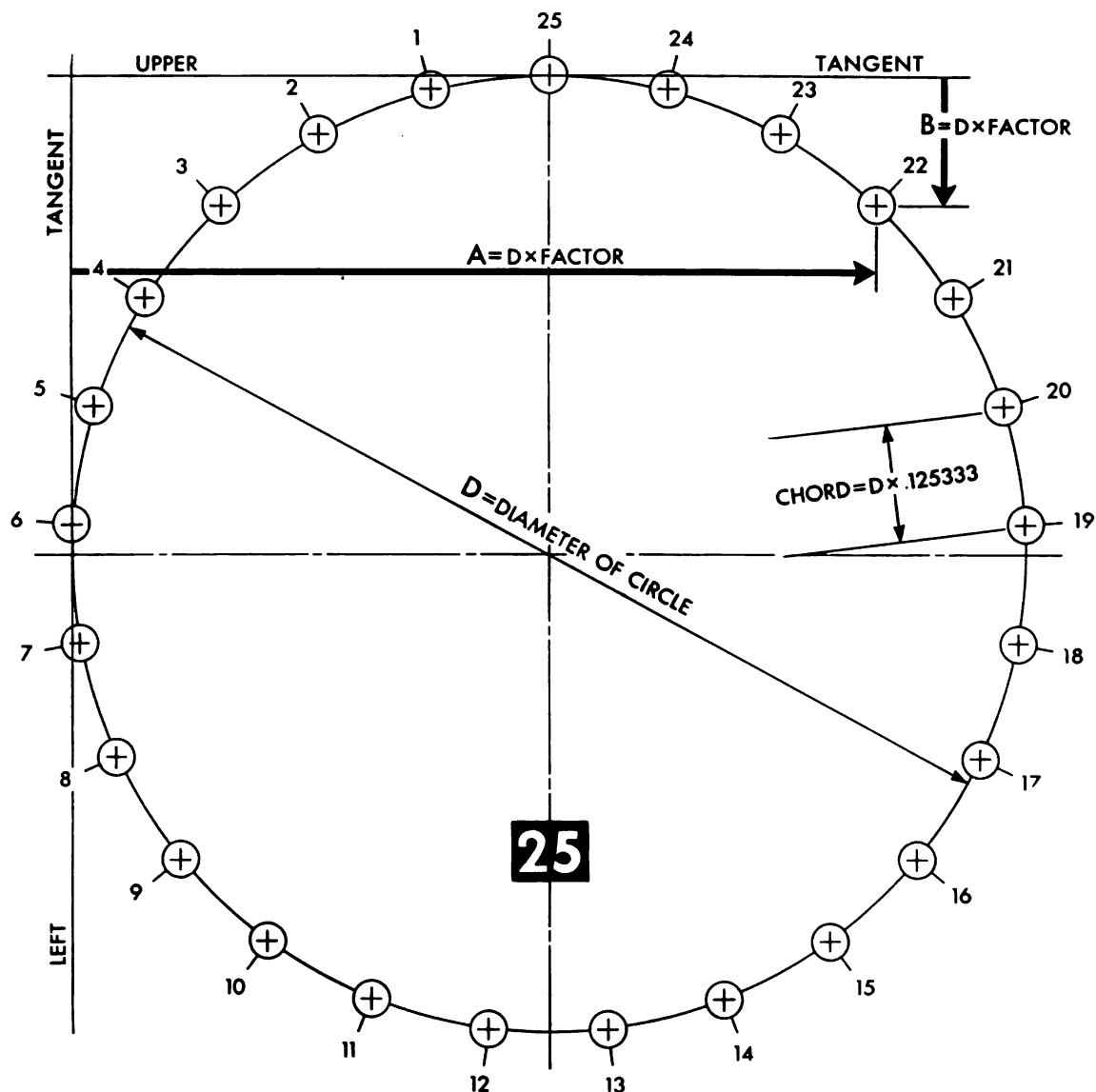
	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.431917	11	.995343	11	172	10 26- 2/23
12		.568083	12	.995343	12	187	49 33-21/23
13		.699197	13	.958606	13	203	28 41-17/23
14		.815544	14	.887856	14	219	7 49-13/23
15		.908485	15	.788340	15	234	46 57- 9/23
16		.971130	16	.667440	16	250	26 5- 5/23
17		.998834	17	.534121	17	266	5 13- 1/23
18		.989542	18	.398272	18	281	44 20-20/23
19		.943943	19	.269967	19	297	23 28-16/23
20		.865418	20	.158723	20	313	2 36-12/23
21		.759792	21	.072790	21	328	41 44- 8/23
22		.634898	22	.018541	22	344	20 52- 4/23
23		.500000	23	.000000	23	360	0 0

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# COORDINATE FACTORS AND ANGLES—24 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.370590	11	.982963	11	165	0 0
12		.500000	12	1.000000	12	180	0 0
13		.629410	13	.982963	13	195	0 0
14		.750000	14	.933013	14	210	0 0
15		.853553	15	.853553	15	225	0 0
16		.933013	16	.750000	16	240	0 0
17		.982963	17	.629410	17	255	0 0
18		1.000000	18	.500000	18	270	0 0
19		.982963	19	.370590	19	285	0 0
20		.933013	20	.250000	20	300	0 0
21		.853553	21	.146447	21	315	0 0
22		.750000	22	.066987	22	330	0 0
23		.629410	23	.017037	23	345	0 0
24		.500000	24	.000000	24	360	0 0

# 25 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

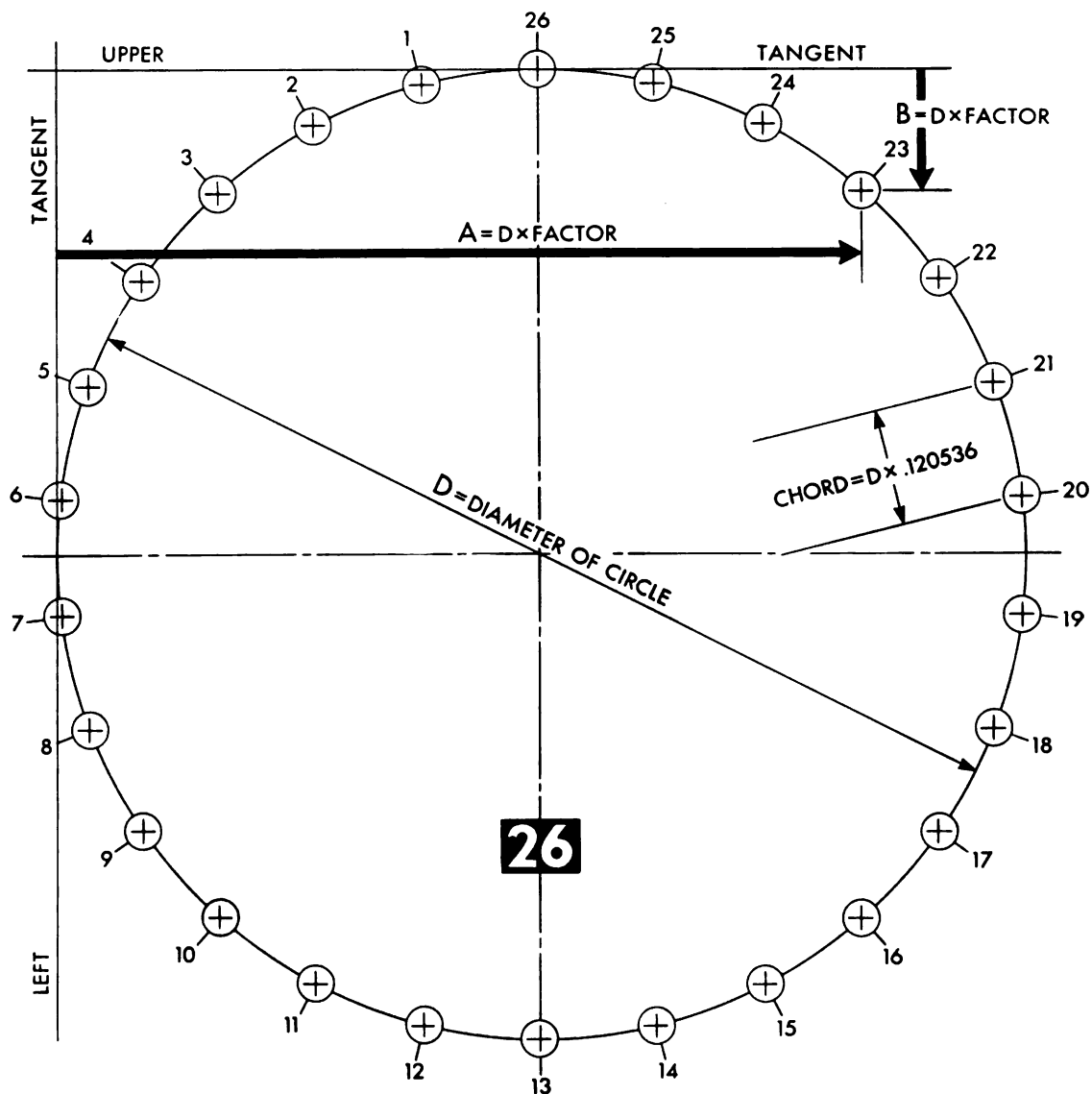


➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
1	.375655	1	.015708	1	14	24	0
2	.259123	2	.061847	2	28	48	0
3	.157726	3	.135516	3	43	12	0
4	.077836	4	.232087	4	57	36	0
5	.024472	5	.345492	5	72	00	0
6	.000987	6	.468605	6	86	24	0
7	.008856	7	.593691	7	100	48	0
8	.047586	8	.712890	8	115	12	0
9	.114743	9	.818712	9	129	36	0
10	.206107	10	.904508	10	144	00	0

# COORDINATE FACTORS AND ANGLES—25 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
11		.315937	11	.964888	11	158	24	0
12		.437333	12	.996057	12	172	48	0
13		.562667	13	.996057	13	187	12	0
14		.684062	14	.964888	14	201	36	0
15		.793893	15	.904508	15	216	00	0
16		.885257	16	.818712	16	230	24	0
17		.952414	17	.712890	17	244	48	0
18		.991144	18	.593691	18	259	12	0
19		.999013	19	.468605	19	273	36	0
20		.975528	20	.345492	20	288	00	0
21		.922164	21	.232087	21	302	24	0
22		.842274	22	.135516	22	316	48	0
23		.740877	23	.061847	23	331	12	0
24		.624345	24	.015708	24	345	36	0
25		.500000	25	.000000	25	360	0	0

## 26 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

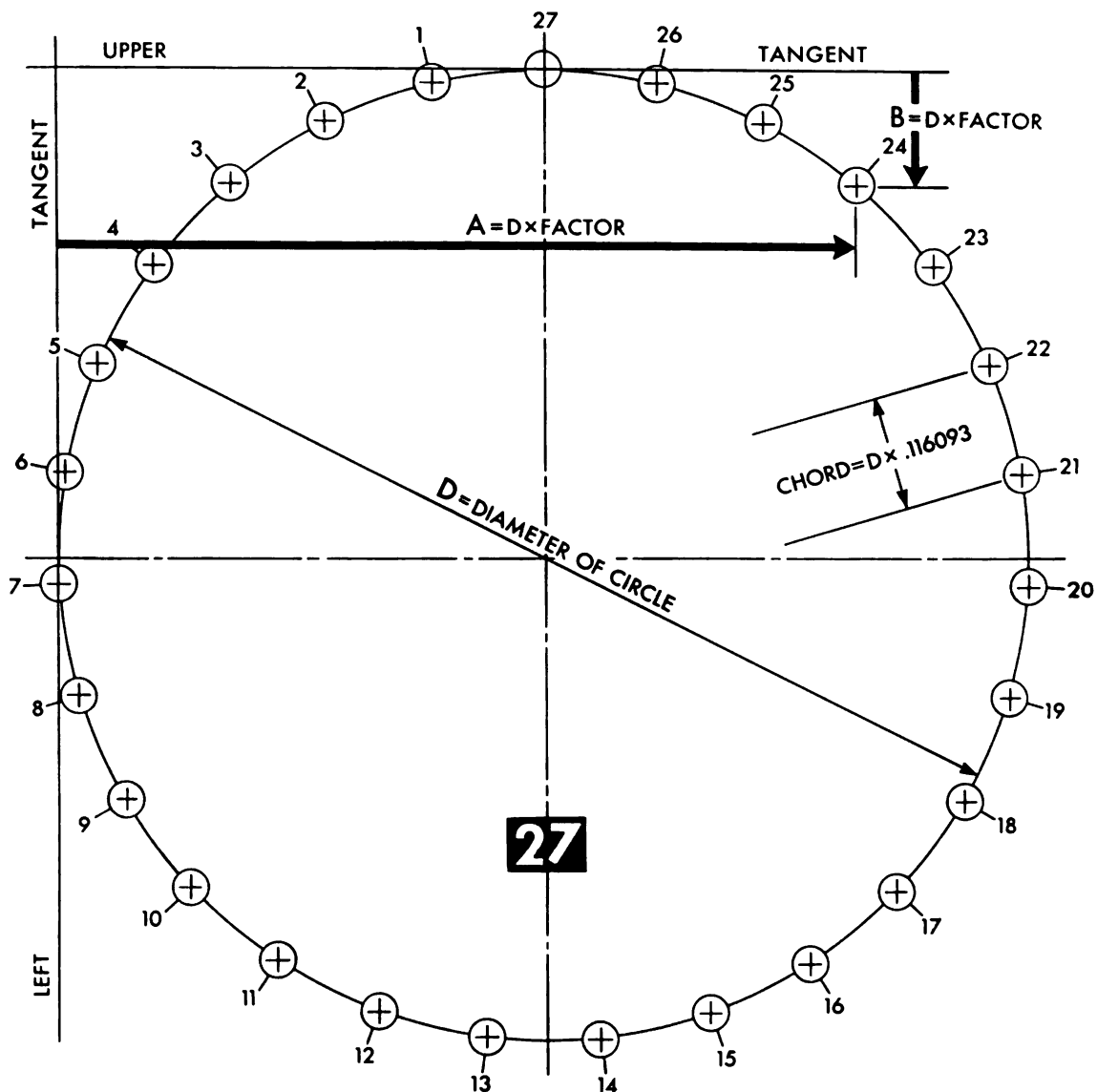


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.380342	1	.014529	1	13	50 46- 4/26
2		.267638	2	.057272	2	27	41 32- 8/26
3		.168439	3	.125745	3	41	32 18-12/26
4		.088508	4	.215968	4	55	23 4-16/26
5		.032492	5	.322698	5	69	13 50-20/26
6		.003646	6	.439732	6	83	4 36-24/26
7		.003646	7	.560268	7	96	55 23- 2/26
8		.032492	8	.677302	8	110	46 9- 6/26
9		.088508	9	.784032	9	124	36 55-10/26
10		.168439	10	.874255	10	138	27 41-14/26

# COORDINATE FACTORS AND ANGLES—26 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.267638	11	.942728	11	152	18 27-18/26
12		.380342	12	.985471	12	166	9 13-22/26
13		.500000	13	1.000000	13	180	00 00000000
14		.619658	14	.985471	14	193	50 46- 4/26
15		.732362	15	.942728	15	207	41 32- 8/26
16		.831561	16	.874255	16	221	32 18-12/26
17		.911492	17	.784032	17	235	23 4-16/26
18		.967508	18	.677302	18	249	13 50-20/26
19		.996354	19	.560268	19	263	4 36-24/26
20		.996354	20	.439732	20	276	55 23- 2/26
21		.967508	21	.322698	21	290	46 9- 6/26
22		.911492	22	.215968	22	304	36 55-10/26
23		.831561	23	.125745	23	318	27 41-14/26
24		.732362	24	.057272	24	332	18 27-18/26
25		.619658	25	.014529	25	346	9 13-22/26
26		.500000	26	.000000	26	360	0 0

## 27 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

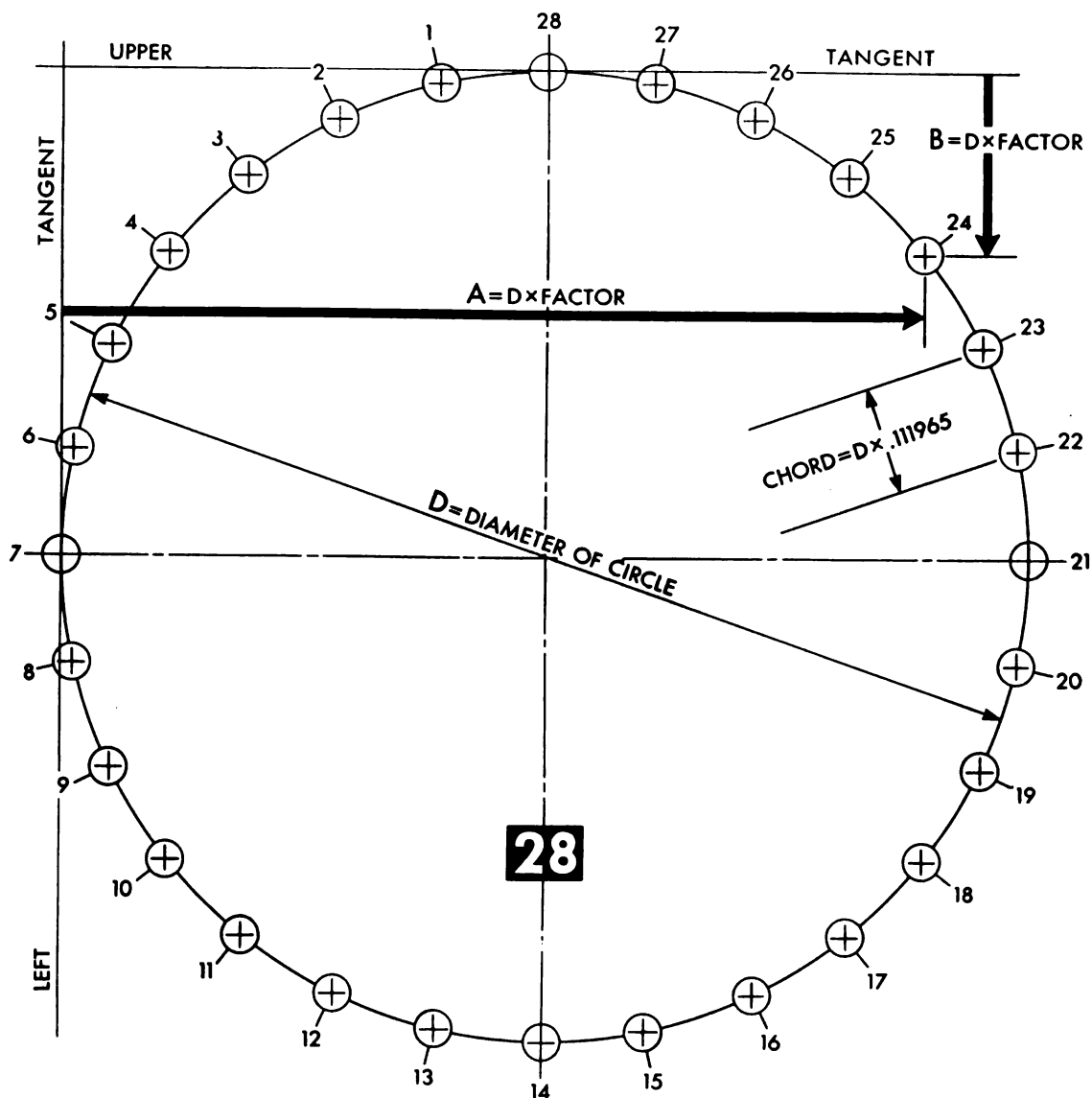


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.384692	1	.013478	1	13	20	0
2		.275600	2	.053184	2	26	40	0
3		.178606	3	.116978	3	40	00	0
4		.098938	4	.201421	4	53	20	0
5		.040892	5	.301960	5	66	40	0
6		.007596	6	.413176	6	80	00	0
7		.000846	7	.529072	7	93	20	0
8		.021005	8	.643402	8	106	40	0
9		.066987	9	.750000	9	120	00	0
10		.136313	10	.843121	10	133	20	0

# COORDINATE FACTORS AND ANGLES—27 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.225246	11	.917744	11	146	40	0
12	.328990	12	.969846	12	160	00	0
13	.441954	13	.996619	13	173	20	0
14	.558046	14	.996619	14	186	40	0
15	.671010	15	.969846	15	200	00	0
16	.774755	16	.917744	16	213	20	0
17	.863687	17	.843121	17	226	40	0
18	.933013	18	.750000	18	240	00	0
19	.978995	19	.643402	19	253	20	0
20	.999154	20	.529072	20	266	40	0
21	.992404	21	.413176	21	280	00	0
22	.959108	22	.301960	22	293	20	0
23	.901062	23	.201421	23	306	40	0
24	.821394	24	.116978	24	320	00	0
25	.724400	25	.053184	25	333	20	0
26	.615308	26	.013478	26	346	40	0
27	.500000	27	.000000	27	360	0	0

## 28 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

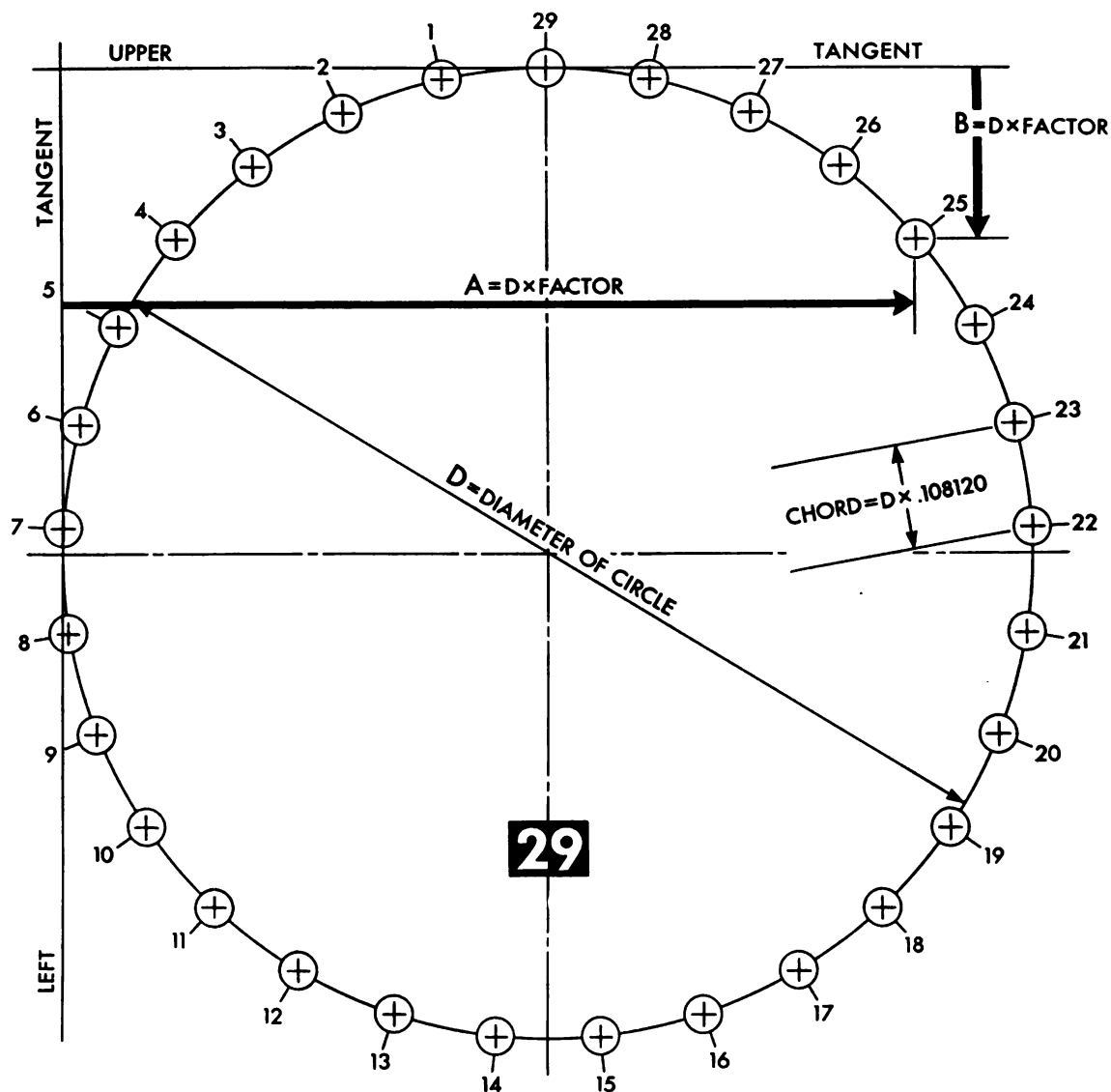


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.388740	1	.012536	1	12	51 25-20/28
2		.283058	2	.049516	2	25	42 51-12/28
3		.188255	3	.109084	3	38	34 17- 4/28
4		.109084	4	.188255	4	51	25 42-24/28
5		.049516	5	.283058	5	64	17 8-16/28
6		.012536	6	.388740	6	77	8 34- 8/28
7		.000000	7	.500000	7	90	00 00000000
8		.012536	8	.611261	8	102	51 25-20/28
9		.049516	9	.716942	9	115	42 51-12/28
10		.109084	10	.811745	10	128	34 17- 4/28

# COORDINATE FACTORS AND ANGLES—28 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.188255	11	.890916	11	141	25 42-24/28
12		.283058	12	.950484	12	154	17 8-16/28
13		.388740	13	.987464	13	167	8 34- 8/28
14		.500000	14	1.000000	14	180	00 00000000
15		.611261	15	.987464	15	192	51 25-20/28
16		.716942	16	.950484	16	205	42 51-12/28
17		.811745	17	.890916	17	218	34 17- 4/28
18		.890916	18	.811745	18	231	25 42-24/28
19		.950484	19	.716942	19	244	17 8-16/28
20		.987464	20	.611261	20	257	8 34- 8/28
21		1.000000	21	.500000	21	270	00 00000000
22		.987464	22	.388740	22	282	51 25-20/28
23		.950484	23	.283058	23	295	42 51-12/28
24		.890916	24	.188255	24	308	34 17- 4/28
25		.811745	25	.109084	25	321	25 42-24/28
26		.716942	26	.049516	26	334	17 8-16/28
27		.611261	27	.012536	27	347	8 34- 8/28
28		.500000	28	.000000	28	360	0 0

## 29 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

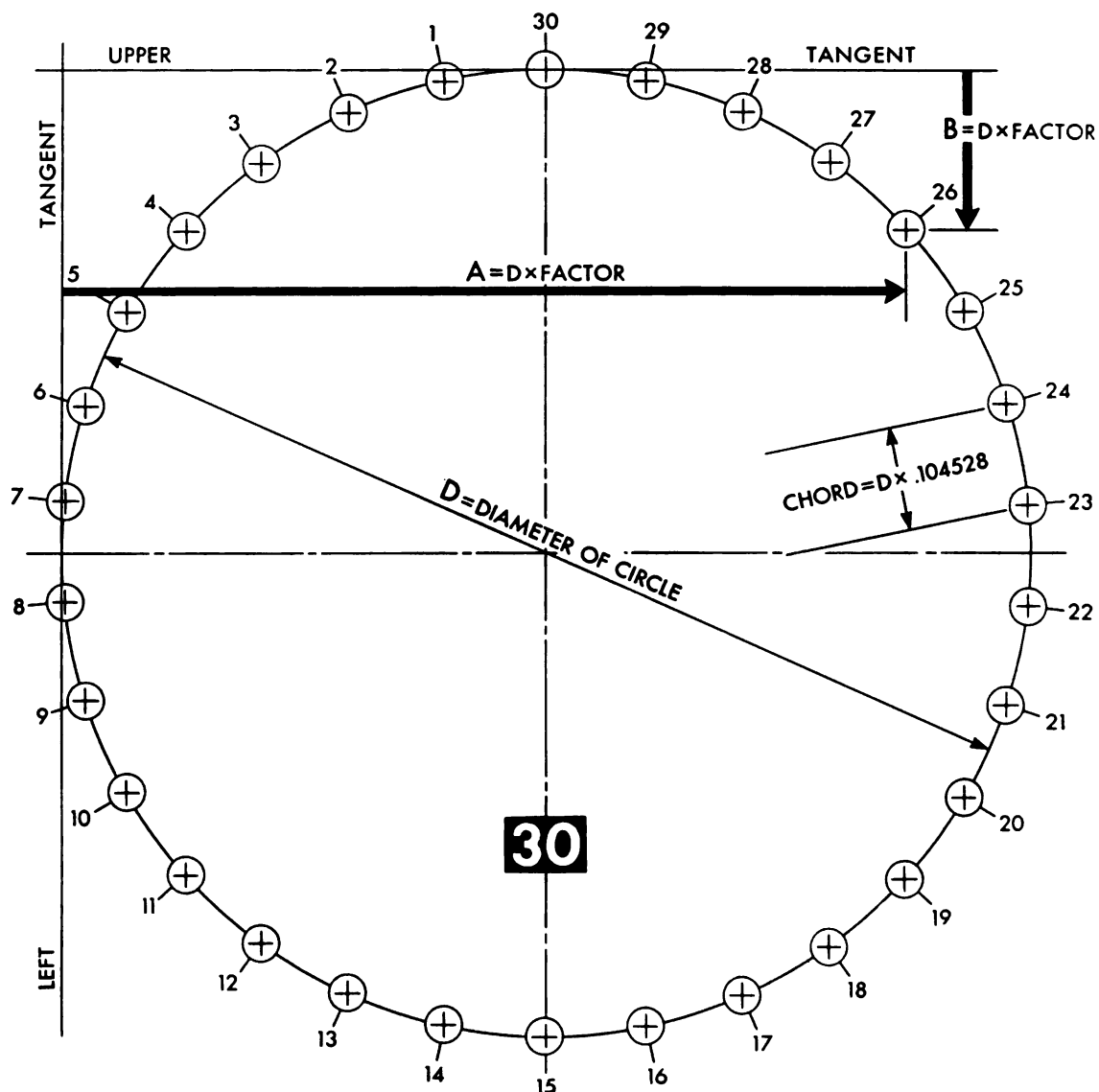


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.392515	1	.011689	1	12	24 49-19/29
2		.290056	2	.046212	2	24	49 39- 9/29
3		.197413	3	.101954	3	37	14 28-28/29
4		.118919	4	.176305	4	49	39 18-18/29
5		.058244	5	.265796	5	62	4 8- 8/29
6		.018225	6	.366236	6	74	28 57-27/29
7		.000733	7	.472931	7	86	53 47-17/29
8		.006587	8	.580891	8	99	18 37- 7/29
9		.035512	9	.685069	9	111	43 26-26/29
10		.086155	10	.780594	10	124	8 16-16/29

# COORDINATE FACTORS AND ANGLES—29 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.156150	11	.862998	11	136	33 6- 6/29
12		.242223	12	.928429	12	148	57 55-25/29
13		.340349	13	.973827	13	161	22 45-15/29
14		.445941	14	.997069	14	173	47 35- 5/29
15		.554060	15	.997069	15	186	12 24-24/29
16		.659651	16	.973827	16	198	37 14-14/29
17		.757777	17	.928429	17	211	2 4- 4/29
18		.843850	18	.862998	18	223	26 53-23/29
19		.913844	19	.780594	19	235	51 43-13/29
20		.964488	20	.685069	20	248	16 33- 3/29
21		.993413	21	.580891	21	260	41 22-22/29
22		.999267	22	.472931	22	273	6 12-12/29
23		.981775	23	.366236	23	285	31 2- 2/29
24		.941756	24	.265796	24	297	55 51-21/29
25		.881081	25	.176305	25	310	20 41-11/29
26		.802587	26	.101954	26	322	45 31- 1/29
27		.709945	27	.046212	27	335	10 20-20/29
28		.607485	28	.011689	28	347	35 10-10/29
29		.500000	29	.000000	29	360	0 0

# 30 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.396044	1	.010926	1	12	0	0
2	.296632	2	.043227	2	24	0	0
3	.206107	3	.095492	3	36	0	0
4	.128428	4	.165435	4	48	0	0
5	.066987	5	.250000	5	60	0	0
6	.024472	6	.345492	6	72	0	0
7	.002739	7	.447736	7	84	0	0
8	.002739	8	.552264	8	96	0	0
9	.024472	9	.654509	9	108	0	0
10	.066987	10	.750000	10	120	0	0

# COORDINATE FACTORS AND ANGLES—30 HOLE DIVISION

➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.128428	11	.834565	11	132	0 0
12	.206107	12	.904509	12	144	0 0
13	.296632	13	.956773	13	156	0 0
14	.396044	14	.989074	14	168	0 0
15	.500000	15	1.000000	15	180	0 0
16	.603956	16	.989074	16	192	0 0
17	.703368	17	.956773	17	204	0 0
18	.793893	18	.904509	18	216	0 0
19	.871572	19	.834565	19	228	0 0
20	.933013	20	.750000	20	240	0 0
21	.975528	21	.654509	21	252	0 0
22	.997261	22	.552264	22	264	0 0
23	.997261	23	.447736	23	276	0 0
24	.975528	24	.345492	24	288	0 0
25	.933013	25	.250000	25	300	0 0
26	.871572	26	.165435	26	312	0 0
27	.793893	27	.095492	27	324	0 0
28	.703368	28	.043227	28	336	0 0
29	.603956	29	.010926	29	348	0 0
30	.500000	30	.000000	30	360	0 0

The diagram illustrates a circle with 31 points, numbered 1 through 31. The points are distributed as follows:
 

- Point 31 is at the top center.
- Points 1 through 30 are arranged in an arc along the top, with points 1, 2, 3, 4, 5 on the left and 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5 on the right.

 Key dimensions and formulas shown:
 

- UPPER TANGENT**: A horizontal line at the top.
- TANGENT**: A vertical line on the left.
- LEFT**: A vertical line on the right.
- A = D × FACTOR**: A horizontal dimension line from point 5 to point 27.
- B = D × FACTOR**: A vertical dimension line from the horizontal line through point 27 to the top tangent line.
- D = DIAMETER OF CIRCLE**: A diagonal line from point 5 to point 21.
- CHORD = D × .101167**: A dimension line between points 24 and 25.
- 31**: A large number in a box at the bottom center.

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# COORDINATE FACTORS AND ANGLES—31 HOLE DIVISION

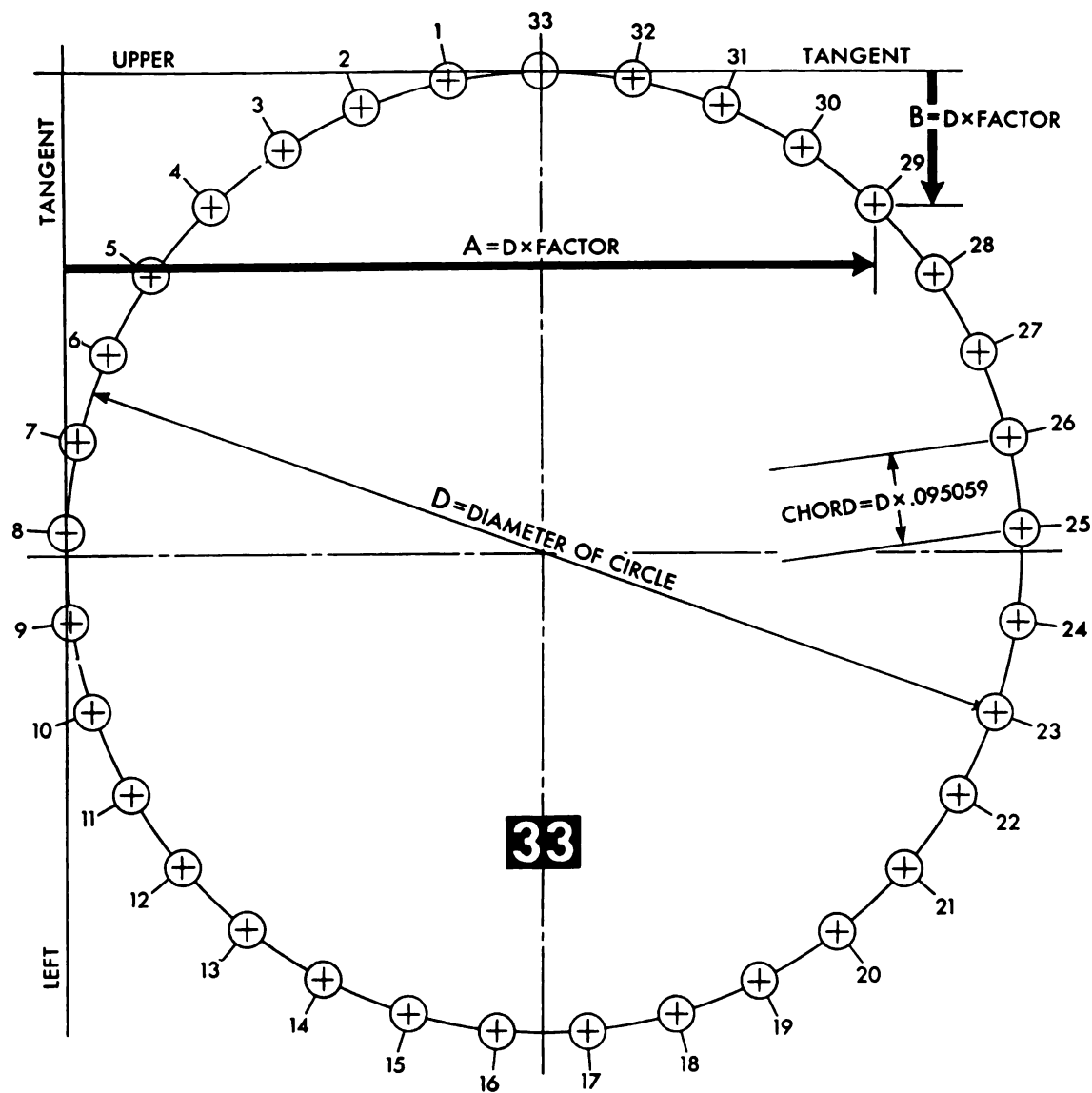
➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.104612	11	.806053	11	127	44 30-30/31
12	.174314	12	.879379	12	139	21 17-13/31
13	.257349	13	.937173	13	150	58 3-27/31
14	.350318	14	.977070	14	162	34 50-10/31
15	.449416	15	.997435	15	174	11 36-24/31
16	.550584	16	.997435	16	185	48 23- 7/31
17	.649682	17	.977070	17	197	25 9-21/31
18	.742651	18	.937173	18	209	1 56- 4/31
19	.825686	19	.879379	19	220	38 42-18/31
20	.895388	20	.806053	20	232	15 29- 1/31
21	.948902	21	.720197	21	243	52 15-15/31
22	.984039	22	.625326	22	255	29 1-29/31
23	.999358	23	.525325	23	267	5 48-12/31
24	.994234	24	.424286	24	278	42 34-26/31
25	.968876	25	.326347	25	290	19 21- 9/31
26	.924322	26	.235518	26	301	56 7-23/31
27	.862396	27	.155517	27	313	32 54- 6/31
28	.785634	28	.089618	28	325	9 40-20/31
29	.697178	29	.040521	29	336	46 27- 3/31
30	.600649	30	.010235	30	348	23 13-17/31
31	.500000	31	.000000	31	360	0 0

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# COORDINATE FACTORS AND ANGLES—32 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
11		.084265	11	.777785	11	123	45	0
12		.146447	12	.853553	12	135	00	0
13		.222215	13	.915735	13	146	15	0
14		.308658	14	.961940	14	157	30	0
15		.402455	15	.990393	15	168	45	0
16		.500000	16	1.000000	16	180	00	0
17		.597545	17	.990393	17	191	15	0
18		.691342	18	.961940	18	202	30	0
19		.777785	19	.915735	19	213	45	0
20		.853553	20	.853553	20	225	00	0
21		.915735	21	.777785	21	236	15	0
22		.961940	22	.691342	22	247	30	0
23		.990393	23	.597545	23	258	45	0
24		1.000000	24	.500000	24	270	00	0
25		.990393	25	.402455	25	281	15	0
26		.961940	26	.308658	26	292	30	0
27		.915735	27	.222215	27	303	45	0
28		.853553	28	.146447	28	315	00	0
29		.777785	29	.084265	29	326	15	0
30		.691342	30	.038060	30	337	30	0
31		.597545	31	.009607	31	348	45	0
32		.500000	32	.000000	32	360	0	0

### 33 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

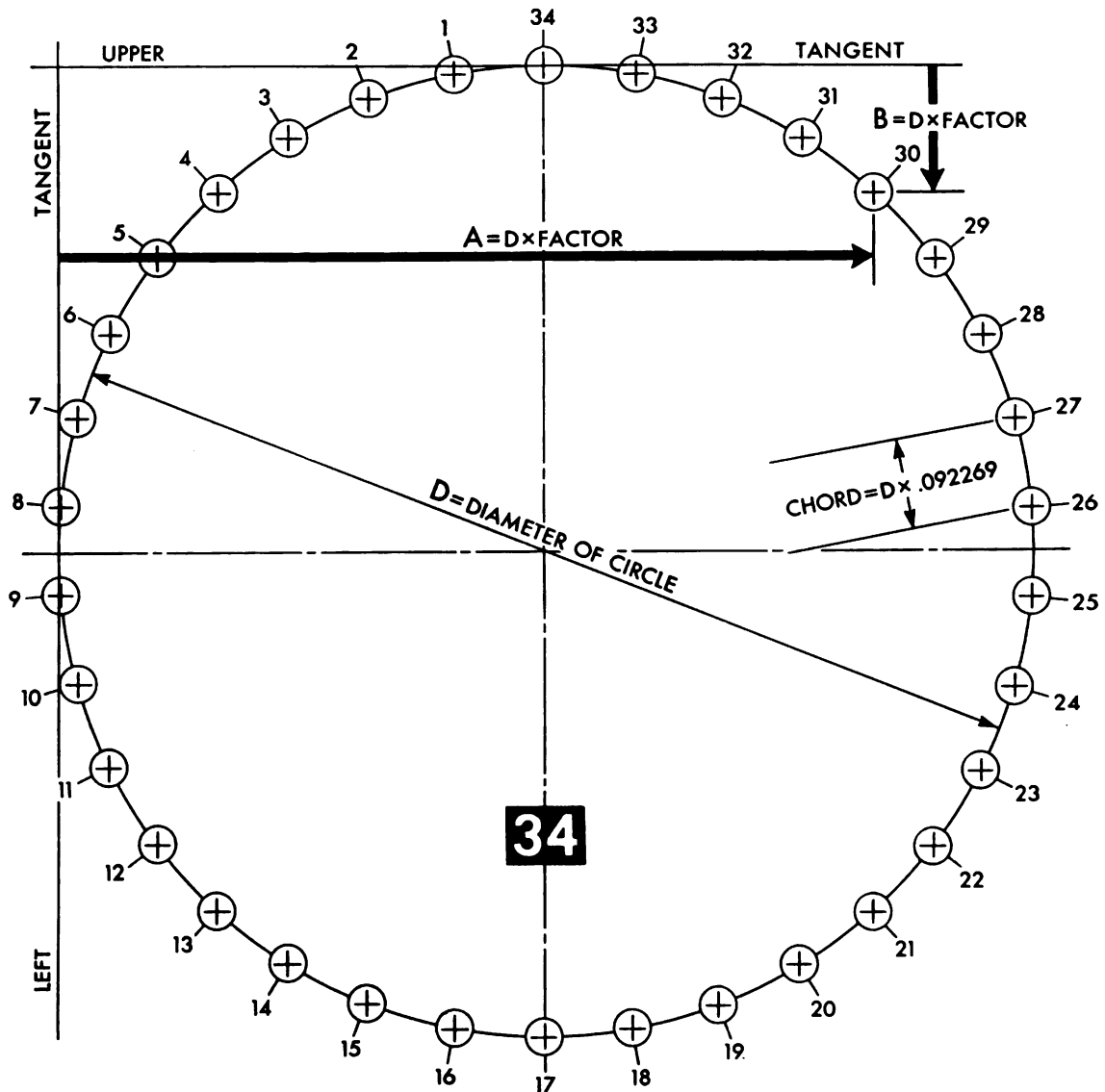


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.405374	1	.009036	1	10	54 32-24/33
2		.314169	2	.035816	2	21	49 5-15/33
3		.229680	3	.079373	3	32	43 38- 6/33
4		.154961	4	.138133	4	43	38 10-30/33
5		.092712	5	.209972	5	54	32 43-21/33
6		.045184	6	.292293	6	65	27 16-12/33
7		.014094	7	.382121	7	76	21 49- 3/33
8		.000566	8	.476209	8	87	16 21-27/33
9		.005089	9	.571157	9	98	10 54-18/33
10		.027500	10	.663534	10	109	5 27- 9/33

# COORDINATE FACTORS AND ANGLES—33 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
11	.066987	11	.750000	11	120	00	00000000	
12	.122125	12	.827430	12	130	54	32-24/33	
13	.190921	13	.893027	13	141	49	5-15/33	
14	.270887	14	.944418	14	152	43	38- 6/33	
15	.359134	15	.979747	15	163	38	10-30/33	
16	.452472	16	.997736	16	174	32	43-21/33	
17	.547528	17	.997736	17	185	27	16-12/33	
18	.640866	18	.979747	18	196	21	49- 3/33	
19	.729113	19	.944418	19	207	16	21-27/33	
20	.809080	20	.893027	20	218	10	54-18/33	
21	.877875	21	.827430	21	229	5	27- 9/33	
22	.933013	22	.750000	22	240	00	00000000	
23	.972500	23	.663534	23	250	54	32-24/33	
24	.994911	24	.571157	24	261	49	5-15/33	
25	.999434	25	.476209	25	272	43	38- 6/33	
26	.985906	26	.382121	26	283	38	10-30/33	
27	.954816	27	.292293	27	294	32	43-21/33	
28	.907288	28	.209972	28	305	27	16-12/33	
29	.845040	29	.138133	29	316	21	49- 3/33	
30	.770320	30	.079373	30	327	16	21-27/33	
31	.685831	31	.035816	31	338	10	54-18/33	
32	.594626	32	.009036	32	349	5	27- 9/33	
33	.500000	33	.000000	33	360	0	0	

### 34 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

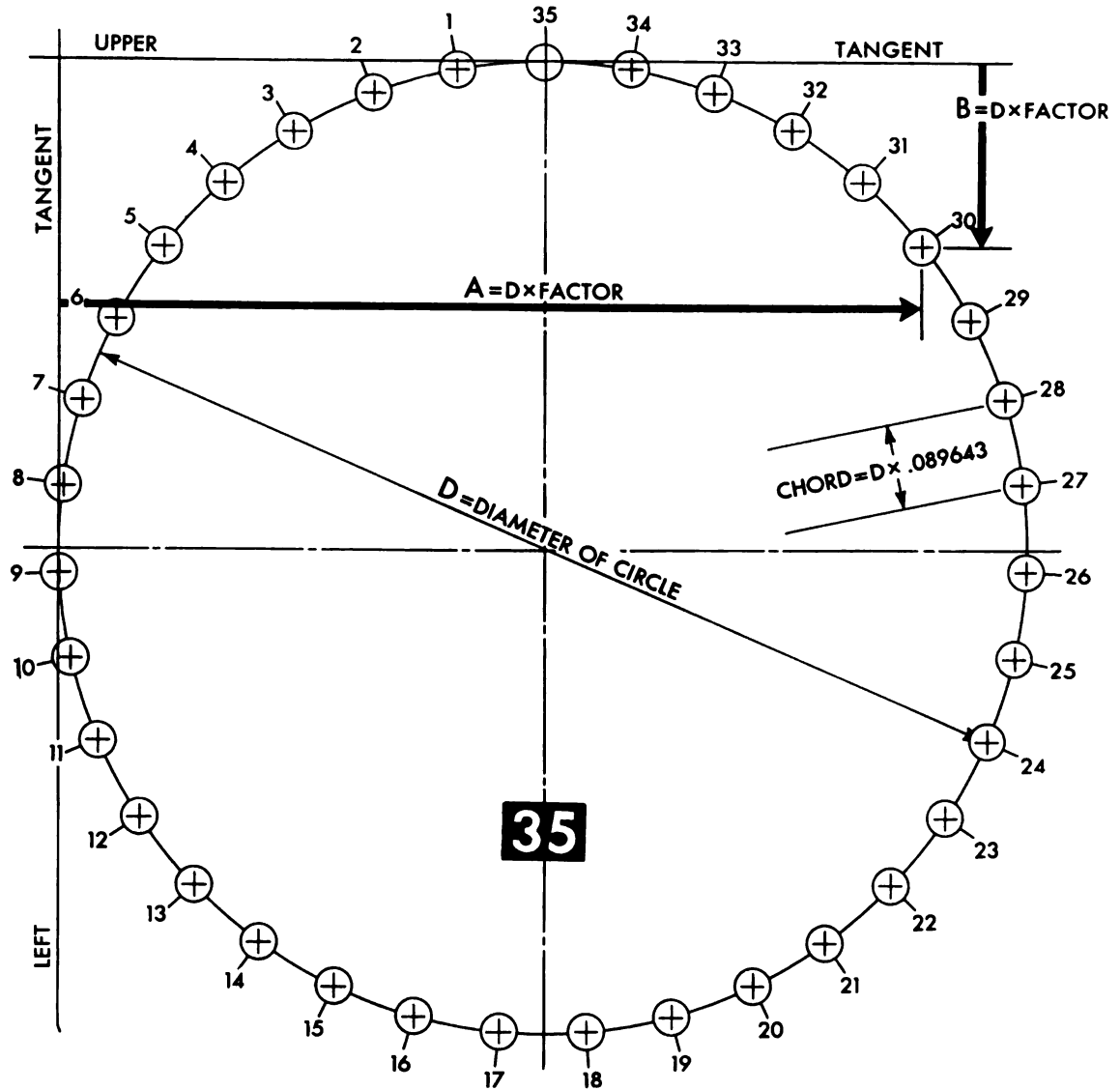


	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.408125	1	.008514	1	10	35	17-22/34
2	.319379	2	.033764	2	21	10	35-10/34
3	.236784	3	.074891	3	31	45	52-32/34
4	.163152	4	.130496	4	42	21	10-20/34
5	.100991	5	.198683	5	52	56	28- 8/34
6	.052418	6	.277131	6	63	31	45-30/34
7	.019087	7	.363169	7	74	7	3-18/34
8	.002133	8	.453866	8	84	42	21- 6/34
9	.002133	9	.546134	9	95	17	38-28/34
10	.019087	10	.636832	10	105	52	56-16/34

# COORDINATE FACTORS AND ANGLES—34 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.052418	11	.722869	116	28	14- 4/34
12	.100991	12	.801317	127	3	31-26/34
13	.163152	13	.869504	137	38	49-14/34
14	.236784	14	.925109	148	14	7- 2/34
15	.319379	15	.966236	158	49	24-24/34
16	.408125	16	.991487	169	24	42-12/34
17	.500000	17	1.000000	180	00	00000000
18	.591875	18	.991487	190	35	17-22/34
19	.680621	19	.966236	201	10	35-10/34
20	.763216	20	.925109	211	45	52-32/34
21	.836848	21	.869504	222	21	10-20/34
22	.899009	22	.801317	232	56	28- 8/34
23	.947582	23	.722869	243	31	45-30/34
24	.980913	24	.636832	254	7	3-18/34
25	.997867	25	.546134	264	42	21- 6/34
26	.997867	26	.453866	275	17	38-28/34
27	.980913	27	.363169	285	52	56-16/34
28	.947582	28	.277131	296	28	14- 4/34
29	.899009	29	.198683	307	3	31-26/34
30	.836848	30	.130496	317	38	49-14/34
31	.763216	31	.074891	328	14	7- 2/34
32	.680621	32	.033764	338	49	24-24/34
33	.591875	33	.008514	349	24	42-12/34
34	.500000	34	.000000	360	0	0

# 35 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

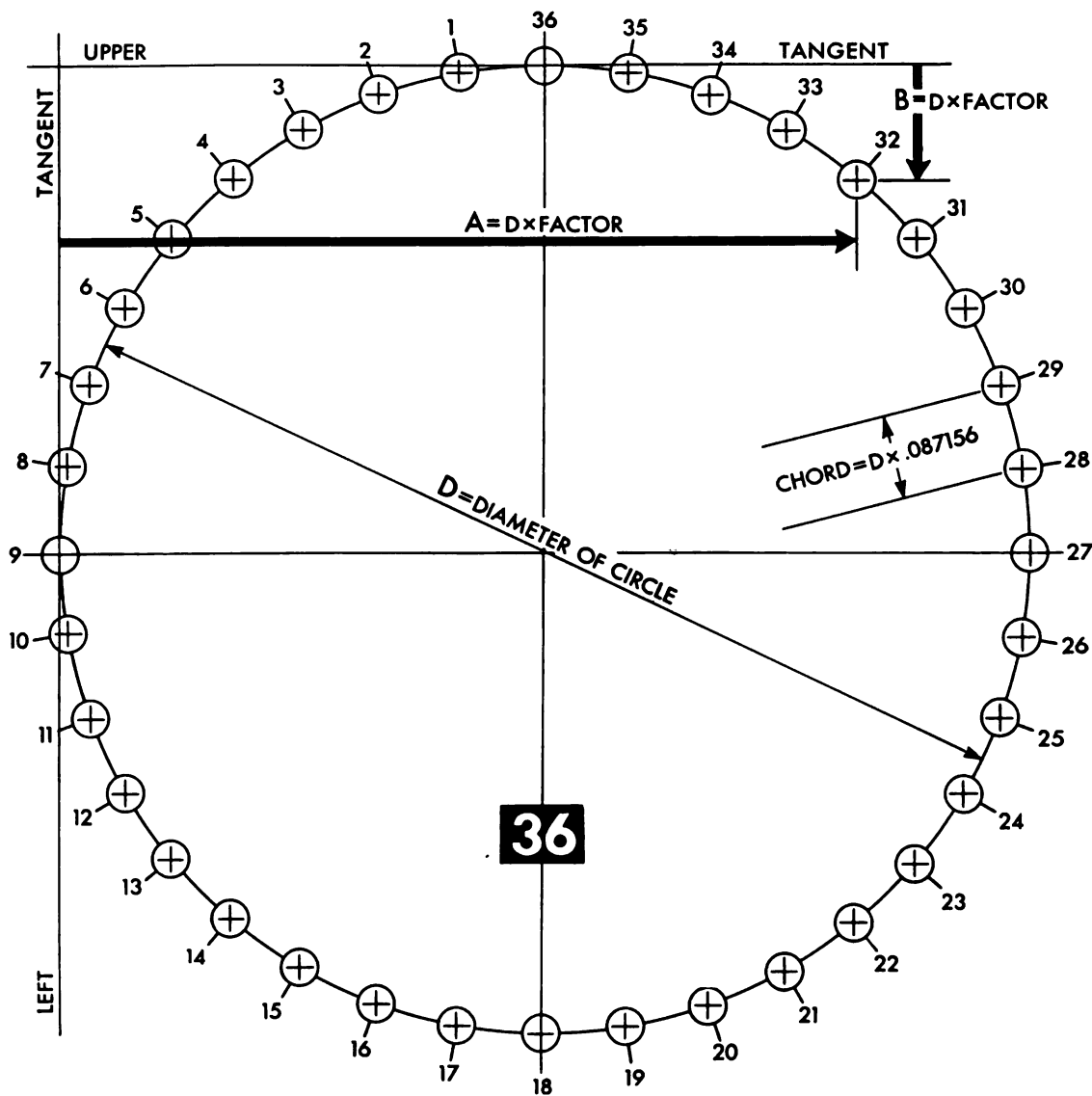


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.410722	1	.008035	1	10	17 8-20/35
2		.324313	2	.031883	2	20	34 17- 5/35
3		.243550	3	.070776	3	30	51 25-25/35
4		.171031	4	.123464	4	41	8 34-10/35
5		.109084	5	.188255	5	51	25 42-30/35
6		.059702	6	.263066	6	61	42 51-15/35
7		.024472	7	.345492	7	72	00 00000000
8		.004525	8	.432883	8	82	17 8-20/35
9		.000504	9	.522433	9	92	34 17- 5/35
10		.012536	10	.611261	10	102	51 25-25/35

# COORDINATE FACTORS AND ANGLES—35 HOLE DIVISION

➡	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.040236	11	.696513	11	113	8	30-10/35
12	.082713	12	.775449	12	123	25	42-30/35
13	.138603	13	.845531	13	133	42	51-15/35
14	.206107	14	.904509	14	144	00	00000000
15	.283058	15	.950484	15	154	17	8-20/35
16	.366982	16	.981981	16	164	34	17- 5/35
17	.455180	17	.997987	17	174	51	25-25/35
18	.544820	18	.997987	18	185	8	34-10/35
19	.633018	19	.981981	19	195	25	42-30/35
20	.716942	20	.950484	20	205	42	51-15/35
21	.793893	21	.904509	21	216	00	00000000
22	.861397	22	.845531	22	226	17	8-20/35
23	.917287	23	.775449	23	236	34	17- 5/35
24	.959764	24	.696513	24	246	51	25-25/35
25	.987464	25	.611261	25	257	8	34-10/35
26	.999497	26	.522433	26	267	25	42-30/35
27	.995475	27	.432883	27	277	42	51-15/35
28	.975528	28	.345492	28	288	00	00000000
29	.940298	29	.263066	29	298	17	8-20/35
30	.890916	30	.188255	30	308	34	17- 5/35
31	.828969	31	.123464	31	318	51	25-25/35
32	.756450	32	.070776	32	329	8	34-10/35
33	.675687	33	.031883	33	339	25	42-30/35
34	.589278	34	.008035	34	349	42	51-15/35
35	.500000	35	.000000	35	360	0	0

### 36 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

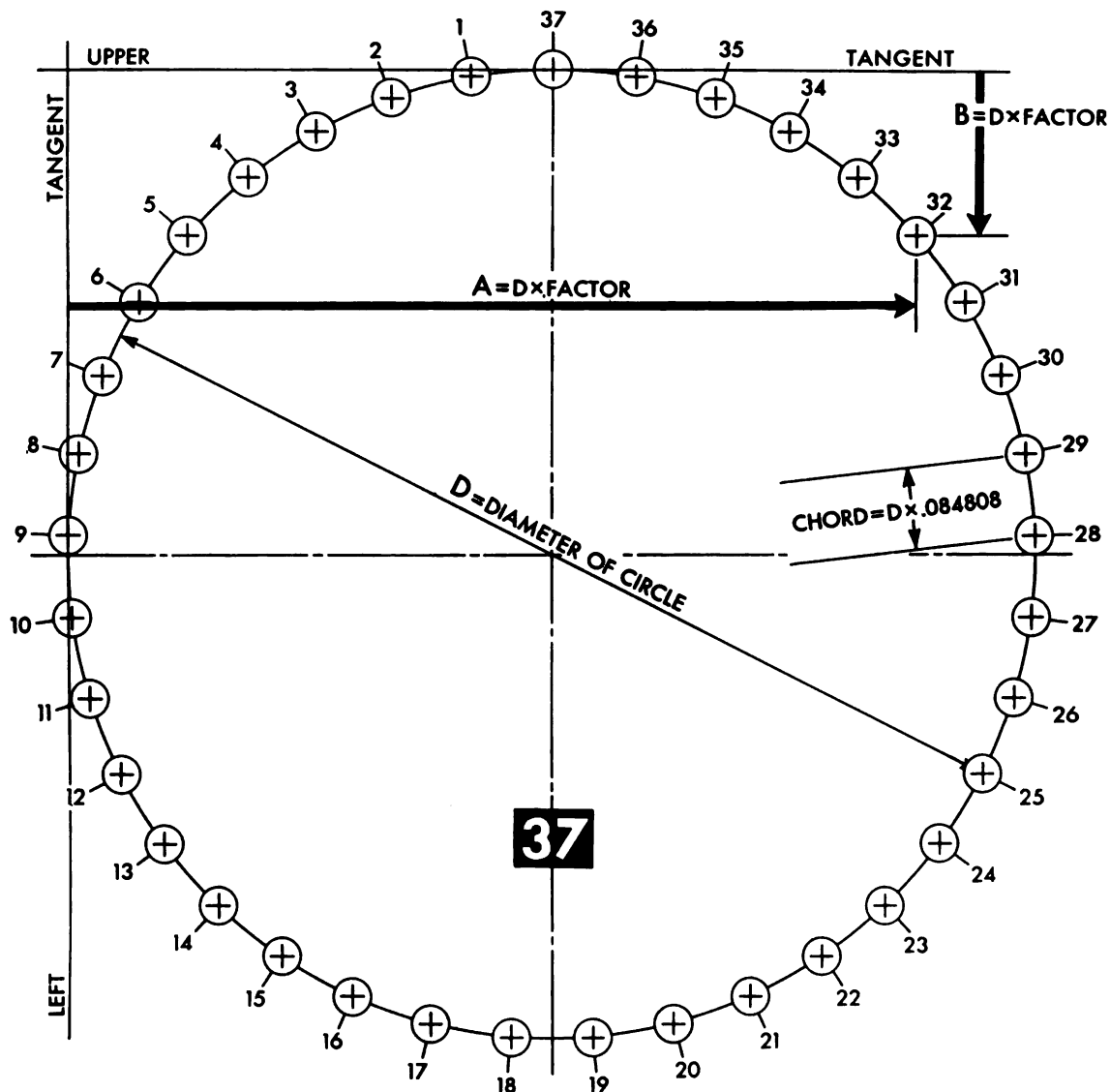


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.413176	1	.007596	1	10	0	0
2	.328990	2	.030154	2	20	0	0
3	.250000	3	.066987	3	30	0	0
4	.178606	4	.116978	4	40	0	0
5	.116978	5	.178606	5	50	0	0
6	.066987	6	.250000	6	60	0	0
7	.030154	7	.328990	7	70	0	0
8	.007596	8	.413176	8	80	0	0
9	.000000	9	.500000	9	90	0	0
10	.007596	10	.586824	10	100	0	0

# COORDINATE FACTORS AND ANGLES—36 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.030154	11	.671010	110	0	0
12	.066987	12	.750000	120	0	0
13	.116978	13	.821394	130	0	0
14	.178606	14	.883022	140	0	0
15	.250000	15	.933013	150	0	0
16	.328990	16	.969846	160	0	0
17	.413176	17	.992404	170	0	0
18	.500000	18	1.000000	180	0	0
19	.586824	19	.992404	190	0	0
20	.671010	20	.969846	200	0	0
21	.750000	21	.933013	210	0	0
22	.821394	22	.883022	220	0	0
23	.883022	23	.821394	230	0	0
24	.933013	24	.750000	240	0	0
25	.969846	25	.671010	250	0	0
26	.992404	26	.586824	260	0	0
27	1.000000	27	.500000	270	0	0
28	.992404	28	.413176	280	0	0
29	.969846	29	.328990	290	0	0
30	.933013	30	.250000	300	0	0
31	.883022	31	.178606	310	0	0
32	.821394	32	.116978	320	0	0
33	.750000	33	.066987	330	0	0
34	.671010	34	.030154	340	0	0
35	.586824	35	.007596	350	0	0
36	.500000	36	.000000	360	0	0

# 37 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

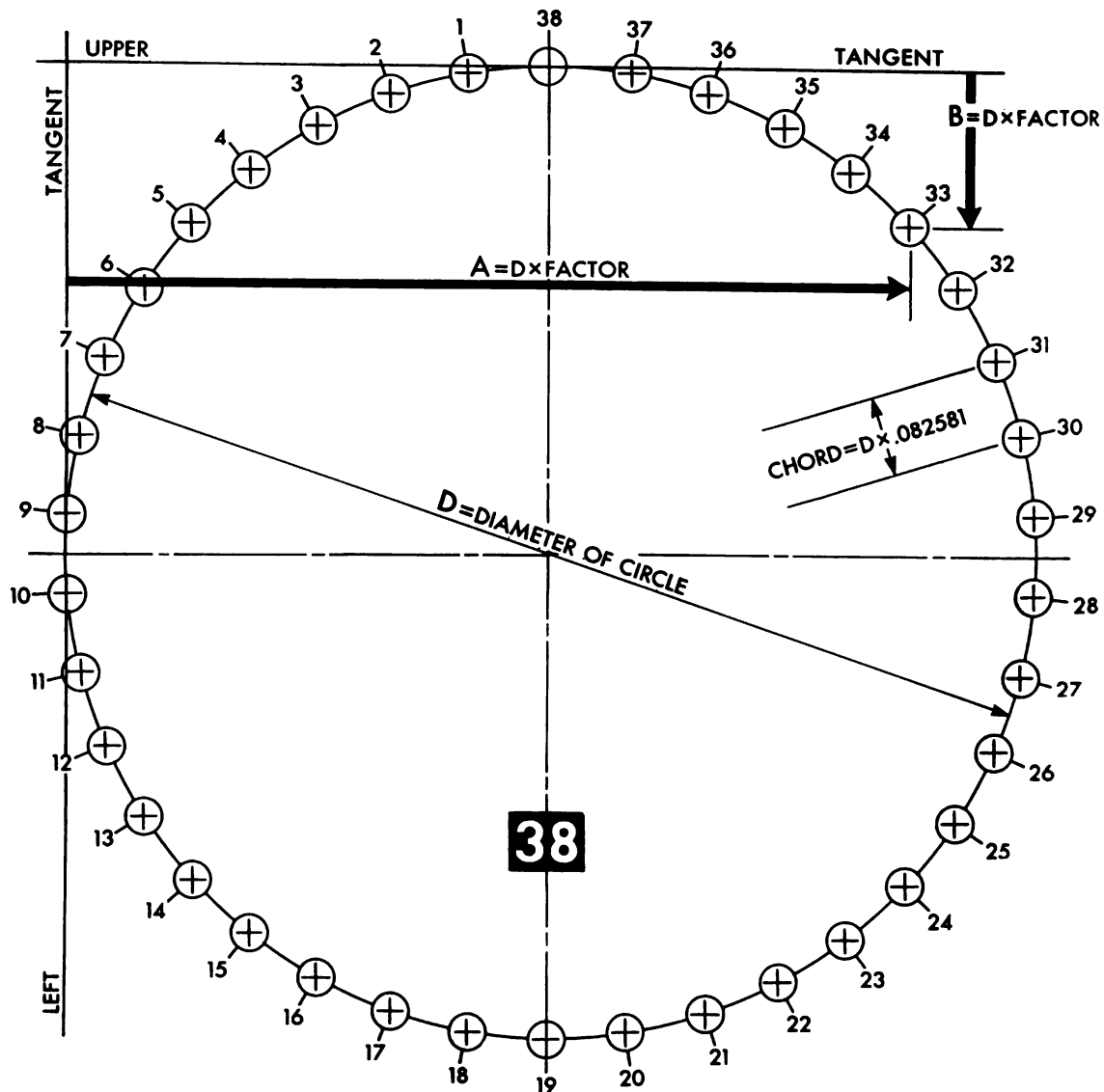


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.415500	1	.007192	1	9	43	47- 1/37
2	.333430	2	.028561	2	19	27	34- 2/37
3	.256153	3	.063493	3	29	11	21- 3/37
4	.185890	4	.110982	4	38	55	8- 4/37
5	.124664	5	.169661	5	48	38	55- 5/37
6	.074235	6	.237846	6	58	22	42- 6/37
7	.036055	7	.313572	7	68	6	29- 7/37
8	.011222	8	.394660	8	77	50	16- 8/37
9	.000451	9	.478779	9	87	34	3- 9/37
10	.004050	10	.563509	10	97	17	50-10/37

# COORDINATE FACTORS AND ANGLES—37 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.021917	11	.646411	11	107	1 37-11/37
12	.053537	12	.725102	12	116	45 24-12/37
13	.098001	13	.797317	13	126	29 11-13/37
14	.154031	14	.860978	14	136	12 58-14/37
15	.220013	15	.914255	15	145	56 45-15/37
16	.294049	16	.955614	16	155	40 32-16/37
17	.374011	17	.983866	17	165	24 19-17/37
18	.457597	18	.998199	18	175	8 6-18/37
19	.542403	19	.998199	19	184	51 53-19/37
20	.625989	20	.983866	20	194	35 40-20/37
21	.705951	21	.955614	21	204	19 27-21/37
22	.779987	22	.914255	22	214	3 14-22/37
23	.845969	23	.860978	23	223	47 1-23/37
24	.901999	24	.797317	24	233	30 48-24/37
25	.946463	25	.725102	25	243	14 35-25/37
26	.978083	26	.646411	26	252	58 22-26/37
27	.995950	27	.563509	27	262	42 9-27/37
28	.999549	28	.478779	28	272	25 56-28/37
29	.988778	29	.394660	29	282	9 43-29/37
30	.963945	30	.313572	30	291	53 30-30/37
31	.925765	31	.237846	31	301	37 17-31/37
32	.875336	32	.169661	32	311	21 4-32/37
33	.814110	33	.110982	33	321	4 51-33/37
34	.743847	34	.063493	34	330	48 38-34/37
35	.666570	35	.028561	35	340	32 25-35/37
36	.584500	36	.007192	36	350	16 12-36/37
37	.500000	37	.000000	37	360	0 0

# 38 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

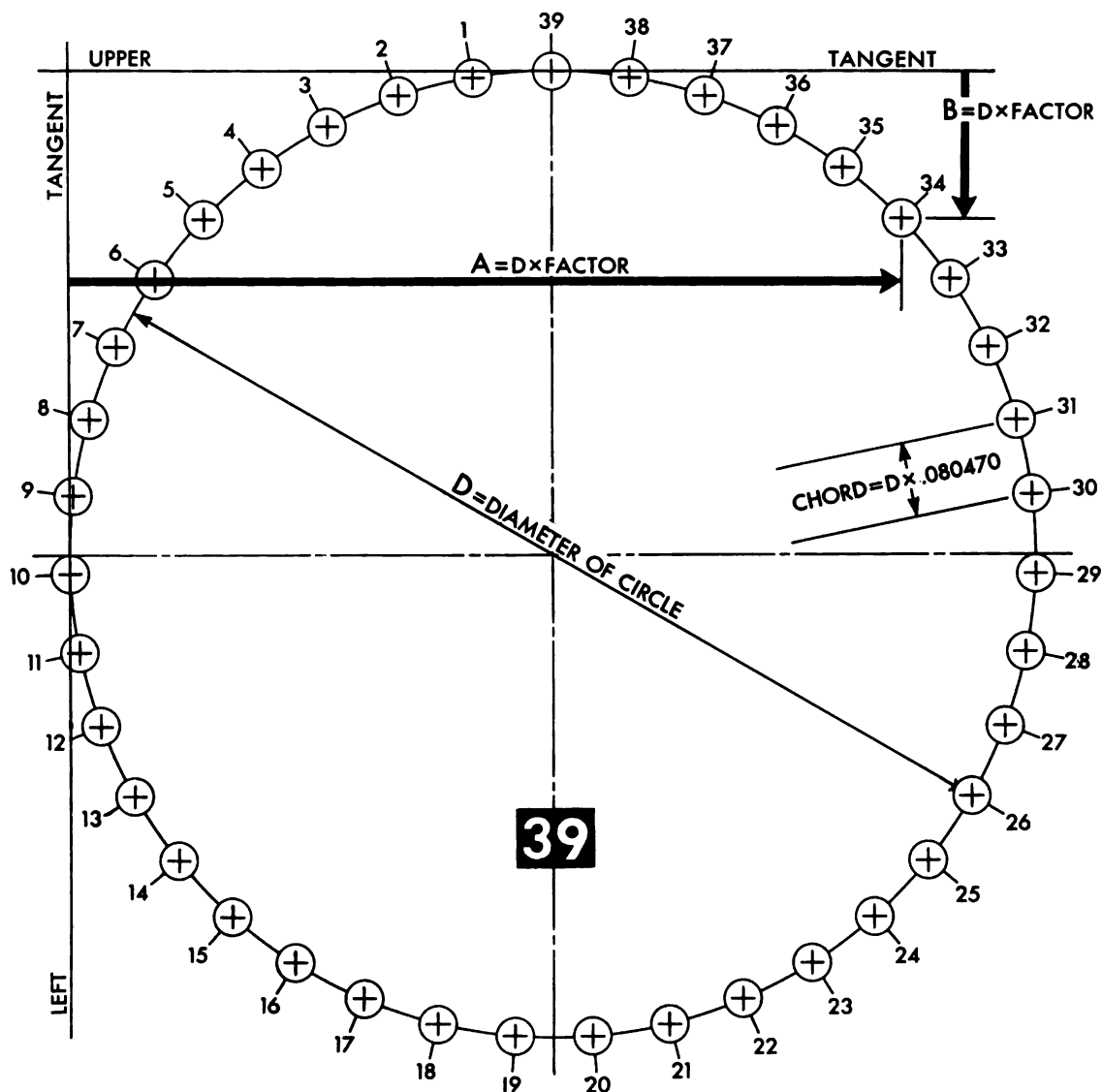


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.417703	1	.006819	1	9	25-10/38
2		.337650	2	.027091	2	18	50-20/38
3		.262026	3	.060263	3	28	15-30/38
4		.192894	4	.105430	4	37	41- 2/38
5		.132138	5	.161359	5	47	6-12/38
6		.081417	6	.226526	6	56	31-22/38
7		.042113	7	.299152	7	66	56-32/38
8		.015300	8	.377257	8	75	22- 4/38
9		.001708	9	.458710	9	85	47-14/38
10		.001708	10	.541290	10	94	12-24/38

# COORDINATE FACTORS AND ANGLES—38 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.015300	11	.622743	11	104	12	37-34/38
12	.042113	12	.700848	12	113	41	3- 6/38
13	.081417	13	.773474	13	123	9	28-16/38
14	.132138	14	.838641	14	132	37	53-26/38
15	.192894	15	.894570	15	142	6	18-36/38
16	.262026	16	.939737	16	151	34	44- 8/38
17	.337650	17	.972909	17	161	3	9-18/38
18	.417703	18	.993181	18	170	31	34-28/38
19	.500000	19	1.000000	19	180	00	00000000
20	.582297	20	.993181	20	189	28	25-10/38
21	.662350	21	.972909	21	198	56	50-20/38
22	.737974	22	.939737	22	208	25	15-30/38
23	.807106	23	.894570	23	217	53	41- 2/38
24	.867862	24	.838641	24	227	22	6-12/38
25	.918583	25	.773474	25	236	50	31-22/38
26	.957887	26	.700848	26	246	18	56-32/38
27	.984700	27	.622743	27	255	47	22- 4/38
28	.998292	28	.541290	28	265	15	47-14/38
29	.998292	29	.458710	29	274	44	12-24/38
30	.984700	30	.377257	30	284	12	37-34/38
31	.957887	31	.299152	31	293	41	3- 6/38
32	.918583	32	.226526	32	303	9	28-16/38
33	.867862	33	.161359	33	312	37	53-26/38
34	.807106	34	.105430	34	322	6	18-36/38
35	.737974	35	.060263	35	331	34	44- 8/38
36	.662350	36	.027091	36	341	3	9-18/38
37	.582297	37	.006819	37	350	31	34-28/38
38	.500000	38	.000000	38	360	0	0

# 39 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

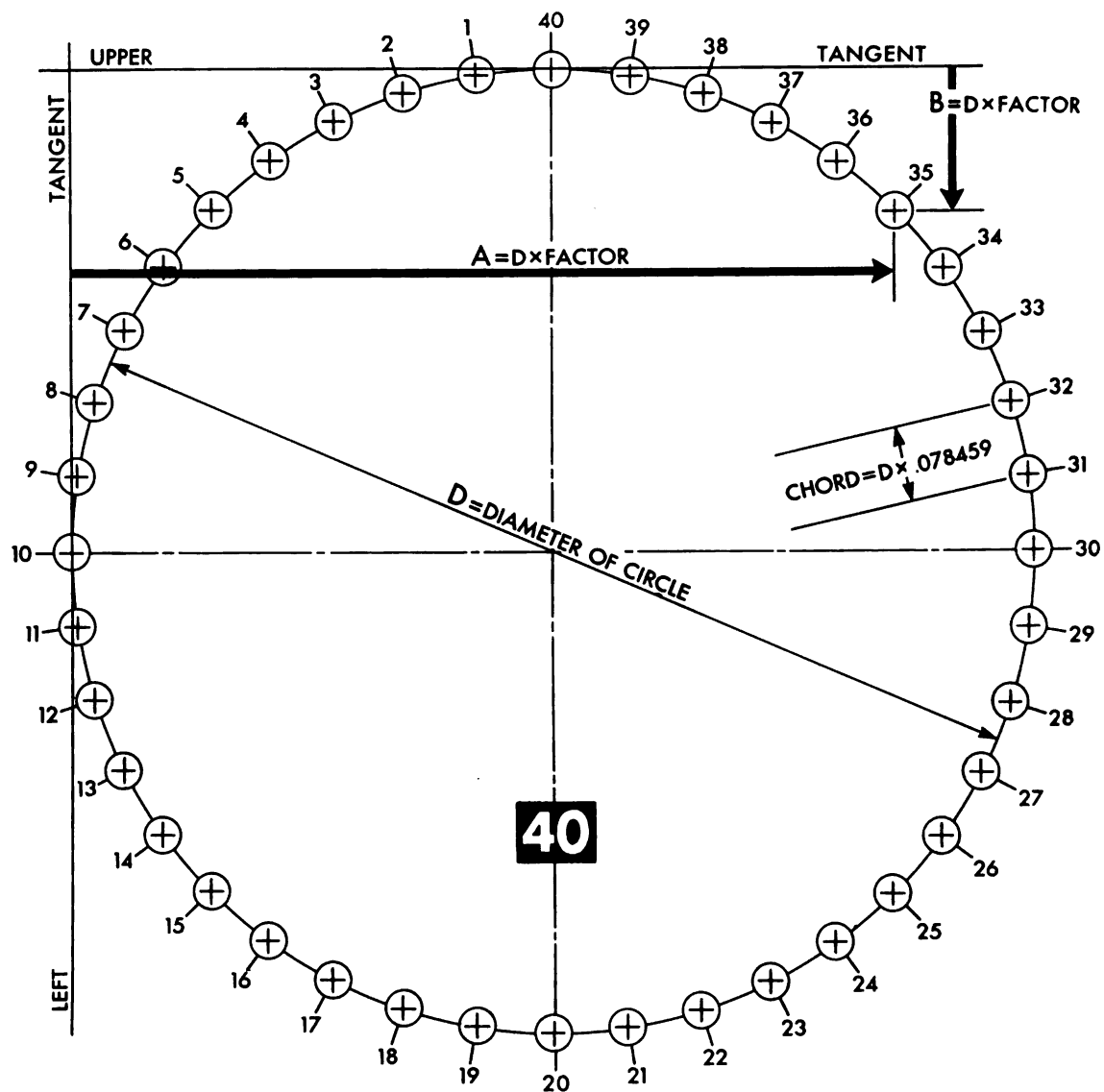


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.419794	1	.006475	1	9	13 50-30/39
2		.341666	2	.025732	2	18	27 41-21/39
3		.267638	3	.057272	3	27	41 32-12/39
4		.199629	4	.100279	4	36	55 23- 3/39
5		.139399	5	.153638	5	46	9 13-33/39
6		.088508	6	.215968	6	55	23 4-24/39
7		.048275	7	.285654	7	64	36 55-15/39
8		.019741	8	.360891	8	73	50 46- 6/39
9		.003646	9	.439732	9	83	4 36-36/39
10		.000406	10	.520133	10	92	18 27-27/39

# COORDINATE FACTORS AND ANGLES—39 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.010105	11	.600013	11	101	32	18-18/39
12	.032492	12	.677302	12	110	46	9- 9/39
13	.066987	13	.750000	13	120	00	00000000
14	.112698	14	.816223	14	129	13	50-30/39
15	.168439	15	.874255	15	138	27	41-21/39
16	.232767	16	.922595	16	147	41	32-12/39
17	.304017	17	.959990	17	156	55	23- 3/39
18	.380342	18	.985471	18	166	9	13-33/39
19	.459767	19	.998379	19	175	23	4-24/39
20	.540233	20	.998379	20	184	36	55-15/39
21	.619658	21	.985471	21	193	50	46- 6/39
22	.695983	22	.959990	22	203	4	36-36/39
23	.767233	23	.922595	23	212	18	27-27/39
24	.831561	24	.874255	24	221	32	18-18/39
25	.887302	25	.816223	25	230	46	9- 9/39
26	.933013	26	.750000	26	240	00	00000000
27	.967508	27	.677302	27	249	13	50-30/39
28	.989895	28	.600013	28	258	27	41-21/39
29	.999595	29	.520133	29	267	41	32-12/39
30	.996354	30	.439732	30	276	55	23- 3/39
31	.980259	31	.360891	31	286	9	13-33/39
32	.951725	32	.285654	32	295	23	4-24/39
33	.911492	33	.215968	33	304	36	55-15/39
34	.860601	34	.153638	34	313	50	46- 6/39
35	.800371	35	.100279	35	323	4	36-36/39
36	.732362	36	.057272	36	332	18	27-27/39
37	.658334	37	.025732	37	341	32	18-18/39
38	.580206	38	.006475	38	350	46	9- 9/39
39	.500000	39	.000000	39	360	0	0

# 40 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.421783	1	.006156	1	9	0
2		.345492	2	.024472	2	18	0
3		.273005	3	.054497	3	27	0
4		.206107	4	.095492	4	36	0
5		.146447	5	.146447	5	45	0
6		.095492	6	.206107	6	54	0
7		.054497	7	.273005	7	63	0
8		.024472	8	.345492	8	72	0
9		.006156	9	.421783	9	81	0
10		.000000	10	.500000	10	90	0

# COORDINATE FACTORS AND ANGLES—40 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.006156	11	.578217	11	99	0	0
12	.024472	12	.654508	12	108	0	0
13	.054497	13	.726995	13	117	0	0
14	.095492	14	.793893	14	126	0	0
15	.146447	15	.853553	15	135	0	0
16	.206107	16	.904508	16	144	0	0
17	.273005	17	.945503	17	153	0	0
18	.345492	18	.975528	18	162	0	0
19	.421783	19	.993844	19	171	0	0
20	.500000	20	1.000000	20	180	0	0
21	.578217	21	.993844	21	189	0	0
22	.654508	22	.975528	22	198	0	0
23	.726995	23	.945503	23	207	0	0
24	.793893	24	.904508	24	216	0	0
25	.853553	25	.853553	25	225	0	0
26	.904508	26	.793893	26	234	0	0
27	.945503	27	.726995	27	243	0	0
28	.975528	28	.654508	28	252	0	0
29	.993844	29	.578217	29	261	0	0
30	1.000000	30	.500000	30	270	0	0
31	.993844	31	.421783	31	279	0	0
32	.975528	32	.345492	32	288	0	0
33	.945503	33	.273005	33	297	0	0
34	.904508	34	.206107	34	306	0	0
35	.853553	35	.146447	35	315	0	0
36	.793893	36	.095492	36	324	0	0
37	.726995	37	.054497	37	333	0	0
38	.654508	38	.024472	38	342	0	0
39	.578217	39	.006156	39	351	0	0
40	.500000	40	.000000	40	360	0	0

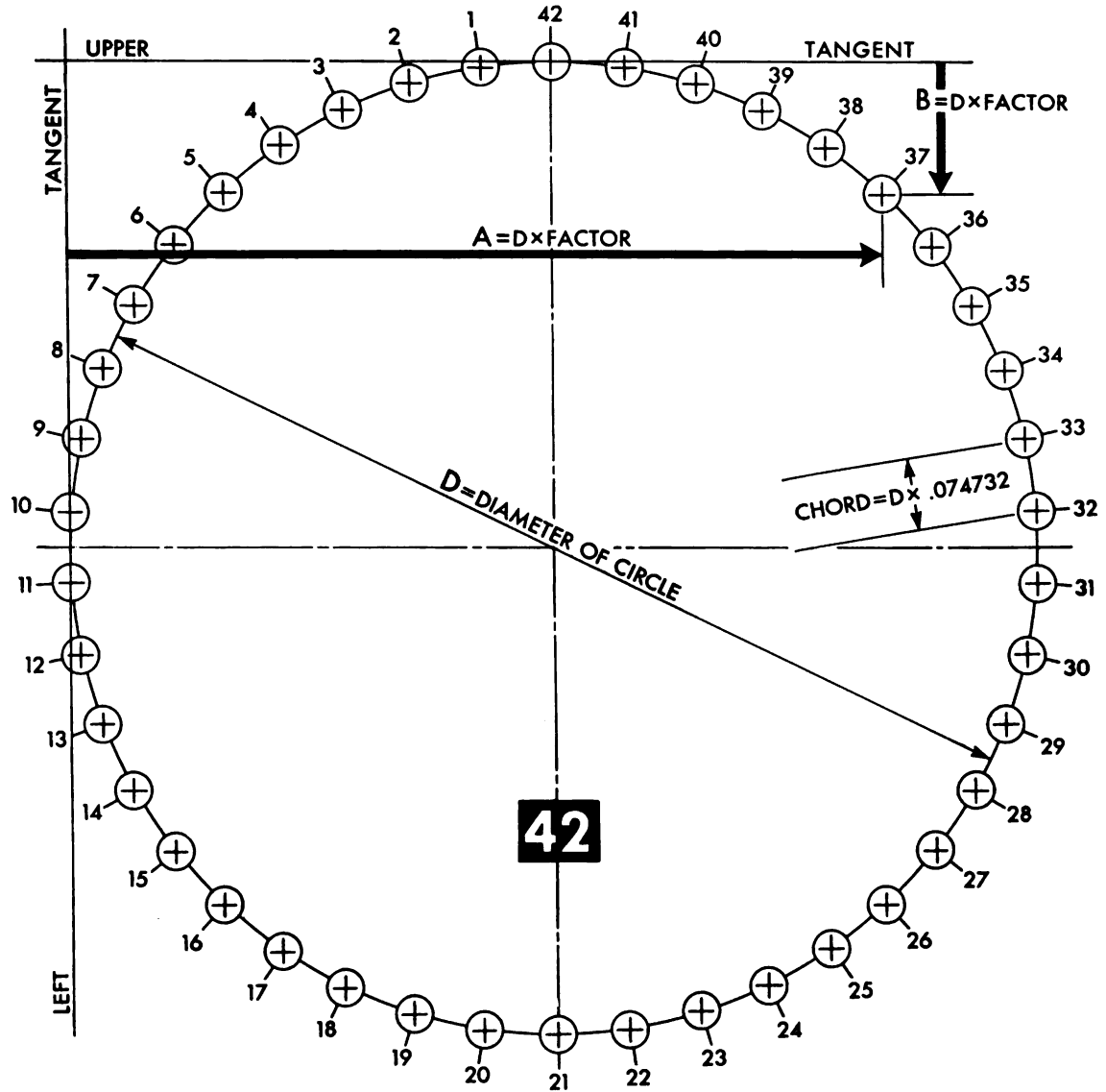


➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
1	.423675	1	.005860	1	8	46	49-31/41
2	.349140	2	.023302	2	17	33	39-21/41
3	.278140	3	.051917	3	26	20	29-11/41
4	.212341	4	.091035	4	35	7	19- 1/41
5	.153284	5	.139739	5	43	54	8-32/41
6	.102354	6	.196887	6	52	40	58-22/41
7	.060744	7	.261140	7	61	27	48-12/41
8	.029430	8	.330992	8	70	14	38- 2/41
9	.009146	9	.404804	9	79	1	27-33/41
10	.000367	10	.480849	10	87	48	17-23/41

# COORDINATE FACTORS AND ANGLES—41 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.003299	11	.557342	11	96	35 7-13/41
12		.017873	12	.632491	12	105	21 57- 3/41
13		.043748	13	.704534	13	114	8 46-34/41
14		.080317	14	.771784	14	122	55 36-24/41
15		.126723	15	.832663	15	131	42 26-14/41
16		.181879	16	.885745	16	140	29 16- 4/41
17		.244491	17	.929785	17	149	16 5-35/41
18		.313091	18	.963751	18	158	2 55-25/41
19		.386073	19	.986848	19	166	49 45-15/41
20		.461725	20	.998533	20	175	36 35- 5/41
21		.538275	21	.998533	21	184	23 24-36/41
22		.613927	22	.986848	22	193	10 14-26/41
23		.686909	23	.963751	23	201	57 4-16/41
24		.755509	24	.929785	24	210	43 54- 6/41
25		.818121	25	.885745	25	219	30 43-37/41
26		.873277	26	.832663	26	228	17 33-27/41
27		.919683	27	.771784	27	237	4 23-17/41
28		.956252	28	.704534	28	245	51 13- 7/41
29		.982127	29	.632491	29	254	38 2-38/41
30		.996701	30	.557342	30	263	24 52-28/41
31		.999633	31	.480849	31	272	11 42-18/41
32		.990854	32	.404804	32	280	58 32- 8/41
33		.970570	33	.330992	33	289	45 21-39/41
34		.939256	34	.261140	34	298	32 11-29/41
35		.897646	35	.196887	35	307	19 1-19/41
36		.846716	36	.139739	36	316	5 51- 9/41
37		.787659	37	.091035	37	324	52 40-40/41
38		.721860	38	.051917	38	333	39 30-30/41
39		.650860	39	.023302	39	342	26 20-20/41
40		.576325	40	.005860	40	351	13 10-10/41
41		.500000	41	.000000	41	360	0 0

# 42 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

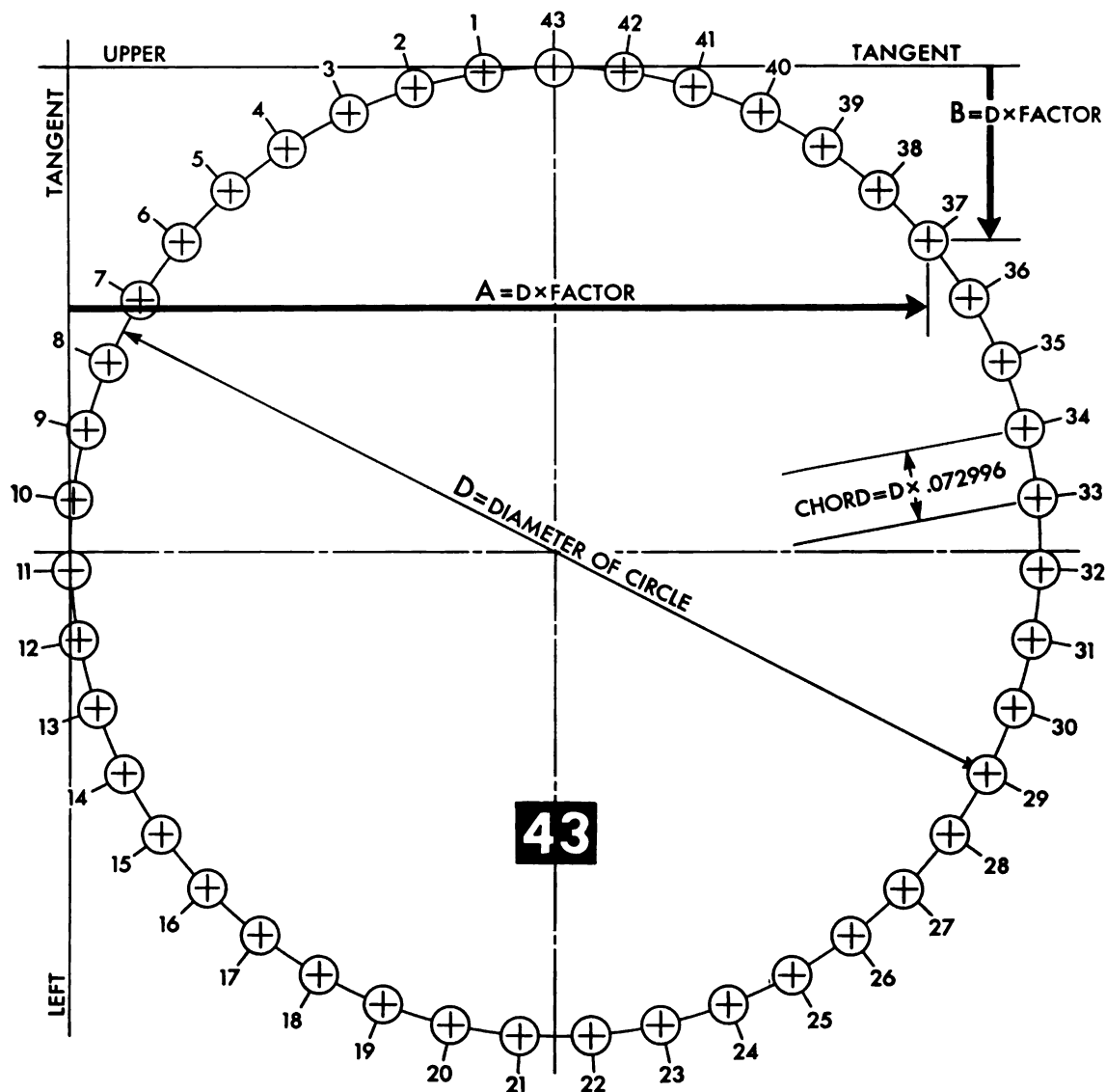


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.425479	1	.005585	1	8	34 17- 6/42
2		.352622	2	.022214	2	17	8 34-12/42
3		.283058	3	.049516	3	25	42 51-18/42
4		.218340	4	.086881	4	34	17 8-24/42
5		.159914	5	.133474	5	42	51 25-30/42
6		.109084	6	.188255	6	51	25 42-36/42
7		.066987	7	.250000	7	60	00 00000000
8		.034563	8	.317329	8	68	34 17- 6/42
9		.012536	9	.388740	9	77	8 34-12/42
10		.001398	10	.462635	10	85	42 51-18/42

# COORDINATE FACTORS AND ANGLES—42 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.001398	11	.537365	11	94	17 8-24/42
12		.012536	12	.611260	12	102	51 25-30/42
13		.034563	13	.682671	13	111	25 42-36/42
14		.066987	14	.750000	14	120	00 00000000
15		.109084	15	.811745	15	128	34 17- 6/42
16		.159914	16	.866526	16	137	8 34-12/42
17		.218340	17	.913119	17	145	42 51-18/42
18		.283058	18	.950484	18	154	17 8-24/42
19		.352622	19	.977786	19	162	51 25-30/42
20		.425479	20	.994415	20	171	25 42-36/42
21		.500000	21	1.000000	21	180	00 00000000
22		.574521	22	.994415	22	188	34 17- 6/42
23		.647378	23	.977786	23	197	8 34-12/42
24		.716942	24	.950484	24	205	42 51-18/42
25		.781660	25	.913119	25	214	17 8-24/42
26		.840086	26	.866526	26	222	51 25-30/42
27		.890916	27	.811745	27	231	25 42-36/42
28		.933013	28	.750000	28	240	00 00000000
29		.965437	29	.682671	29	248	34 17- 6/42
30		.987464	30	.611260	30	257	8 34-12/42
31		.998602	31	.537365	31	265	42 51-18/42
32		.998602	32	.462635	32	274	17 8-24/42
33		.987464	33	.388740	33	282	51 25-30/42
34		.965437	34	.317329	34	291	25 42-36/42
35		.933013	35	.250000	35	300	00 00000000
36		.890916	36	.188255	36	308	34 17- 6/42
37		.840086	37	.133474	37	317	8 34-12/42
38		.781660	38	.086881	38	325	42 51-18/42
39		.716942	39	.049516	39	334	17 8-24/42
40		.647378	40	.022214	40	342	51 25-30/42
41		.574521	41	.005585	41	351	25 42-36/42
42		.500000	42	.000000	42	360	0 0

# 43 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

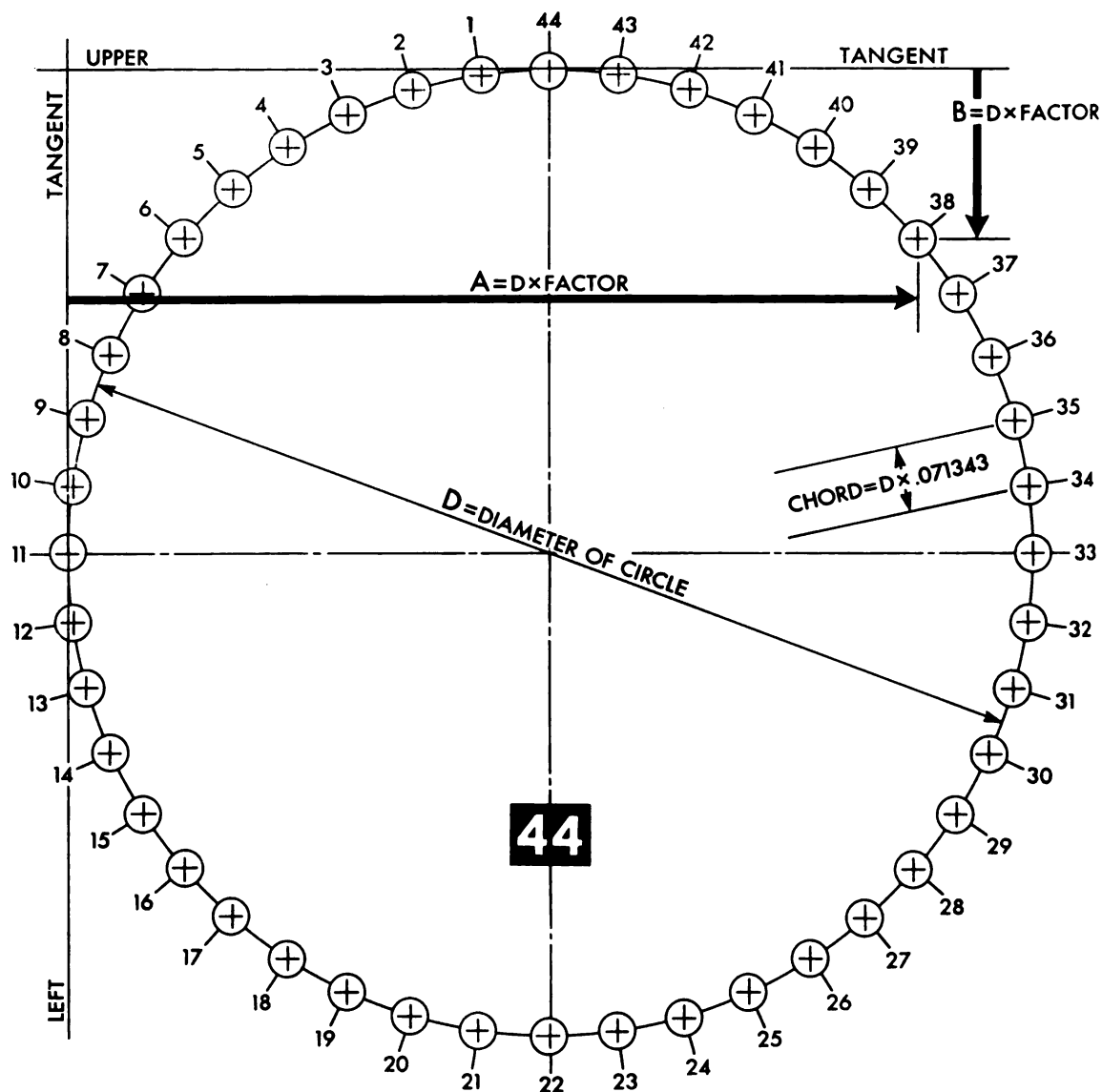


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.427199	1	.005328	1	8	22	19-23/43
2	.355950	2	.021200	2	16	44	39- 3/43
3	.287772	3	.047276	3	25	6	58-26/43
4	.224116	4	.083001	4	33	29	18- 6/43
5	.166342	5	.127614	5	41	51	37-29/43
6	.115676	6	.180163	6	50	13	57- 9/43
7	.073203	7	.239530	7	58	36	16-32/43
8	.039827	8	.304448	8	66	58	36-12/43
9	.016258	9	.373533	9	75	20	55-35/43
10	.003000	10	.445314	10	83	43	15-15/43

# COORDINATE FACTORS AND ANGLES—43 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.000334	11	.518261	11	92	5 34-38/43
12	.008317	12	.590818	12	100	27 54-18/43
13	.026780	13	.661440	13	108	50 13-41/43
14	.055329	14	.728621	14	117	12 33-21/43
15	.093355	15	.790929	15	125	34 53- 1/43
16	.140048	16	.847037	16	133	57 12-24/43
17	.194413	17	.895748	17	142	19 32- 4/43
18	.255291	18	.936025	18	150	41 51-27/43
19	.321384	19	.967008	19	159	4 11- 7/43
20	.391285	20	.988038	20	167	26 30-30/43
21	.463502	21	.998666	21	175	48 50-10/43
22	.536498	22	.998666	22	184	11 9-33/43
23	.608715	23	.988038	23	192	33 29-13/43
24	.678616	24	.967008	24	200	55 48-36/43
25	.744709	25	.936025	25	209	18 8-16/43
26	.805587	26	.895748	26	217	40 27-39/43
27	.859952	27	.847037	27	226	2 47-19/43
28	.906645	28	.790929	28	234	25 6-42/43
29	.944671	29	.728621	29	242	47 26-22/43
30	.973220	30	.661440	30	251	9 46- 2/43
31	.991683	31	.590818	31	259	32 5-25/43
32	.999666	32	.518261	32	267	54 25- 5/43
33	.997000	33	.445314	33	276	16 44-28/43
34	.983742	34	.373533	34	284	39 4- 8/43
35	.960173	35	.304448	35	293	1 23-31/43
36	.926797	36	.239530	36	301	23 43-11/43
37	.884324	37	.180163	37	309	46 2-34/43
38	.833658	38	.127614	38	318	8 22-14/43
39	.775884	39	.083001	39	326	30 41-37/43
40	.712228	40	.047276	40	334	53 1-17/43
41	.644050	41	.021200	41	343	15 20-40/43
42	.572801	42	.005328	42	351	37 40-20/43
43	.500000	43	.000000	43	360	0 0

# 44 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

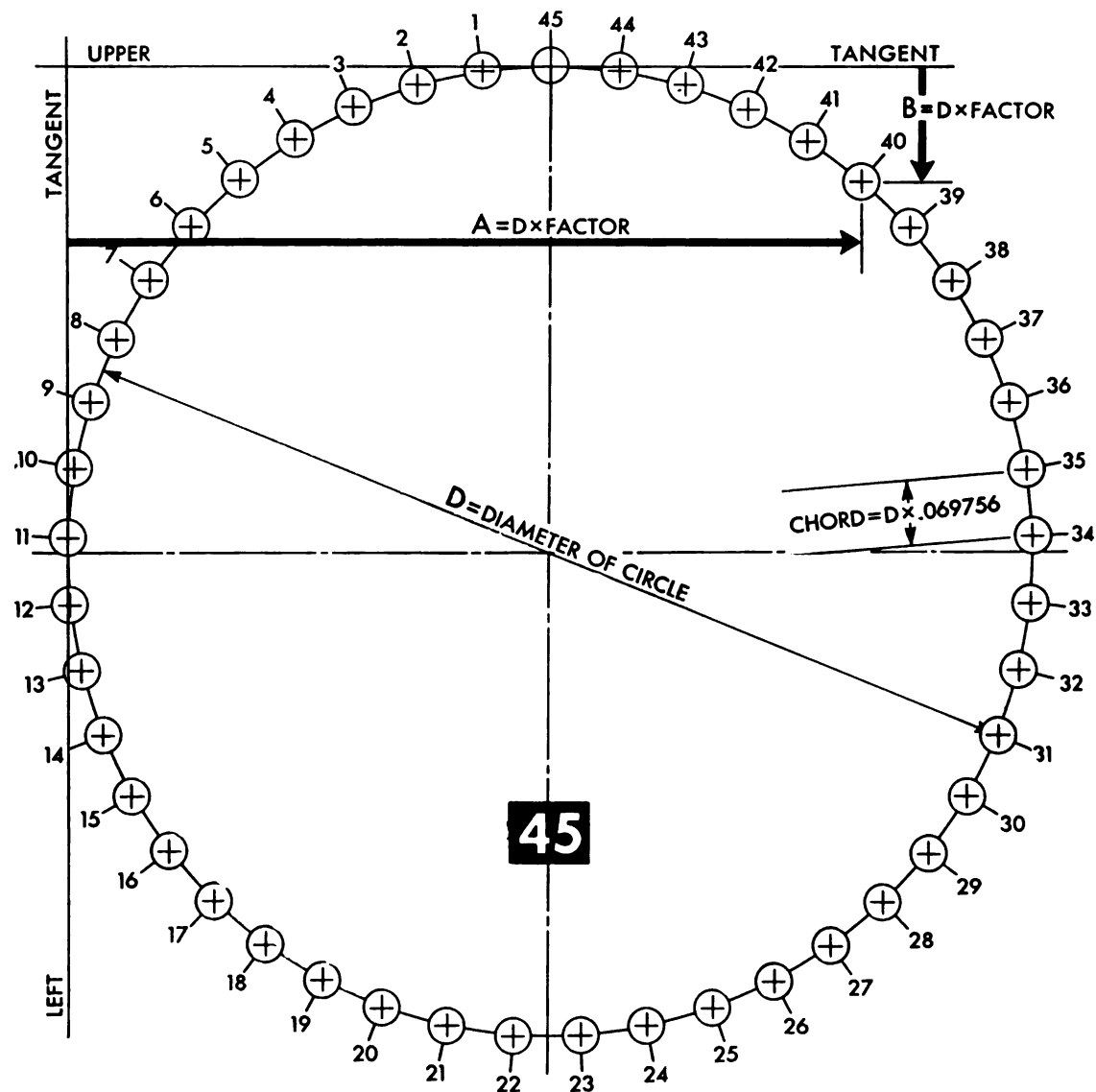


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.428843	1	.005089	1	8	10 54-24/44
2	.359134	2	.020254	2	16	21 49- 4/44
3	.292293	3	.045184	3	24	32 43-28/44
4	.229680	4	.079373	4	32	43 38- 8/44
5	.172570	5	.122125	5	40	54 32-32/44
6	.122125	6	.172570	6	49	5 27-12/44
7	.079373	7	.229680	7	57	16 21-36/44
8	.045184	8	.292293	8	65	27 16-16/44
9	.020254	9	.359134	9	73	38 10-40/44
10	.005089	10	.428843	10	81	49 5-20/44

# COORDINATE FACTORS AND ANGLES—44 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.000000	11	.500000	11	90	00 00000000
12		.005089	12	.571157	12	98	10 54-24/44
13		.020254	13	.640866	13	106	21 49- 4/44
14		.045184	14	.707708	14	114	32 43-28/44
15		.079373	15	.770320	15	122	43 38- 8/44
16		.122125	16	.827430	16	130	54 32-32/44
17		.172570	17	.877875	17	139	5 27-12/44
18		.229680	18	.920627	18	147	16 21-36/44
19		.292293	19	.954816	19	155	27 16-16/44
20		.359134	20	.979746	20	163	38 10-40/44
21		.428843	21	.994911	21	171	49 5-20/44
22		.500000	22	1.000000	22	180	00 00000000
23		.571157	23	.994911	23	188	10 54-24/44
24		.640866	24	.979746	24	196	21 49- 4/44
25		.707708	25	.954816	25	204	32 43-28/44
26		.770320	26	.920627	26	212	43 38- 8/44
27		.827430	27	.877875	27	220	54 32-32/44
28		.877875	28	.827430	28	229	5 27-12/44
29		.920627	29	.770320	29	237	16 21-36/44
30		.954816	30	.707708	30	245	27 16-16/44
31		.979746	31	.640866	31	253	38 10-40/44
32		.994911	32	.571157	32	261	49 5-20/44
33		1.000000	33	.500000	33	270	00 00000000
34		.994911	34	.428843	34	278	10 54-24/44
35		.979746	35	.359134	35	286	21 49- 4/44
36		.954816	36	.292293	36	294	32 43-28/44
37		.920627	37	.229680	37	302	43 38- 8/44
38		.877875	38	.172570	38	310	54 32-32/44
39		.827430	39	.122125	39	319	5 27-12/44
40		.770320	40	.079373	40	327	16 21-36/44
41		.707708	41	.045184	41	335	27 16-16/44
42		.640866	42	.020254	42	343	38 10-40/44
43		.571157	43	.005089	43	351	49 5-20/44
44		.500000	44	.000000	44	360	0 0

# 45 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

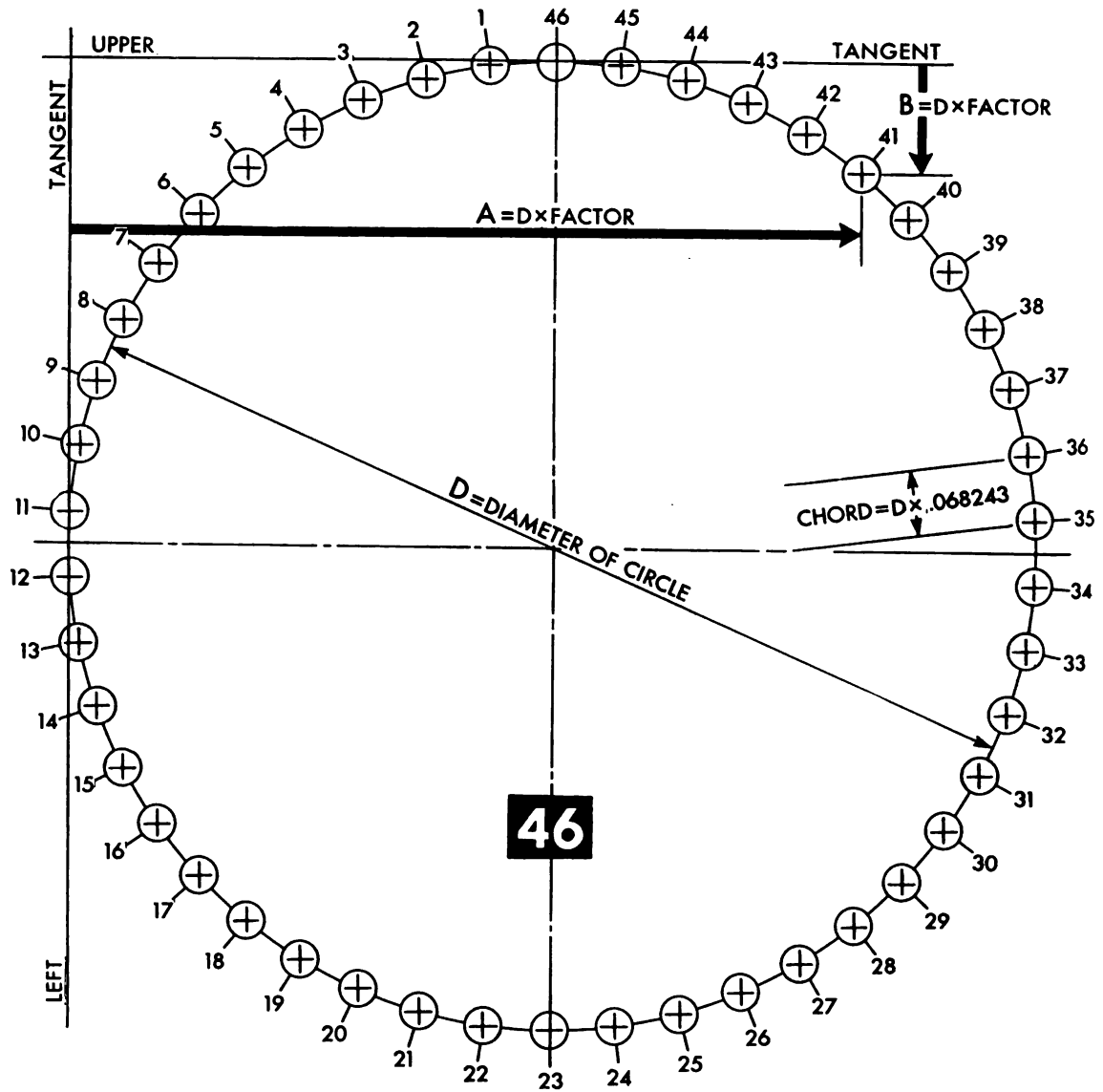


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.430413	1	.004866	1	8	0
2		.362181	2	.019369	2	16	0
3		.296632	3	.043227	3	24	0
4		.235040	4	.075976	4	32	0
5		.178606	5	.116978	5	40	0
6		.128428	6	.165435	6	48	0
7		.085481	7	.220404	7	56	0
8		.050603	8	.280814	8	64	0
9		.024472	9	.345492	9	72	0
10		.007596	10	.413176	10	80	0

# COORDINATE FACTORS AND ANGLES—45 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.000305	11	.482550	11	88	0
12		.002739	12	.552264	12	96	0
13		.014852	13	.620961	13	104	0
14		.036408	14	.687303	14	112	0
15		.066987	15	.750000	15	120	0
16		.105995	16	.807831	16	128	0
17		.152671	17	.859670	17	136	0
18		.206107	18	.904508	18	144	0
19		.265264	19	.941474	19	152	0
20		.328990	20	.969846	20	160	0
21		.396044	21	.989074	21	168	0
22		.465122	22	.998782	22	176	0
23		.534878	23	.998782	23	184	0
24		.603956	24	.989074	24	192	0
25		.671010	25	.969846	25	200	0
26		.734736	26	.941474	26	208	0
27		.793893	27	.904508	27	216	0
28		.847329	28	.859670	28	224	0
29		.894005	29	.807831	29	232	0
30		.933013	30	.750000	30	240	0
31		.963592	31	.687303	31	248	0
32		.985148	32	.620961	32	256	0
33		.997261	33	.552264	33	264	0
34		.999695	34	.482550	34	272	0
35		.992404	35	.413176	35	280	0
36		.975528	36	.345492	36	288	0
37		.949397	37	.280814	37	296	0
38		.914519	38	.220404	38	304	0
39		.871572	39	.165435	39	312	0
40		.821394	40	.116978	40	320	0
41		.764960	41	.075976	41	328	0
42		.703368	42	.043227	42	336	0
43		.637819	43	.019369	43	344	0
44		.569587	44	.004866	44	352	0
45		.500000	45	.000000	45	360	0

# 46 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

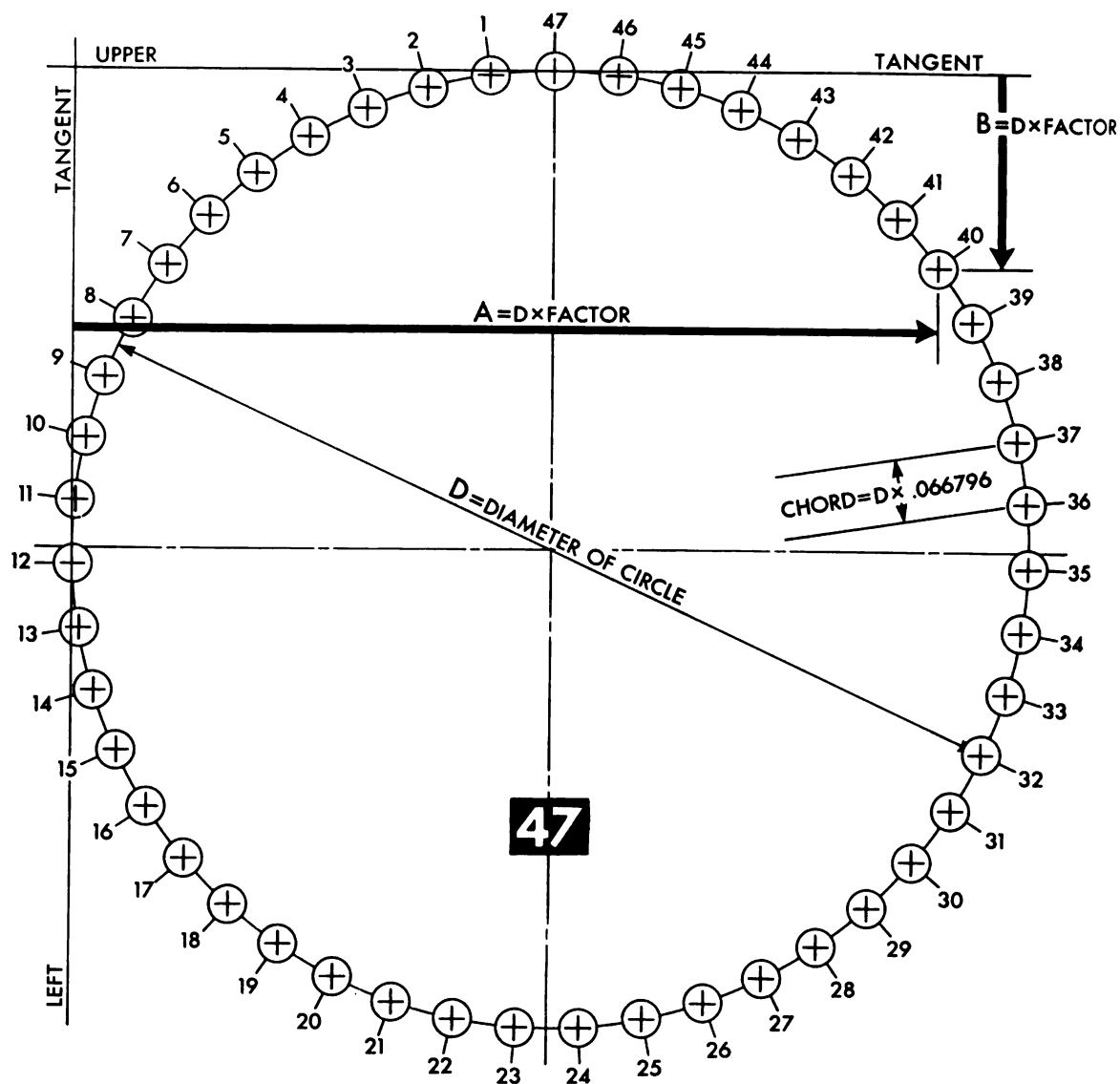


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.431917	1	.004657	1	7	49 33-42/46
2		.365102	2	.018541	2	15	39 7-38/46
3		.300803	3	.041394	3	23	28 41-34/46
4		.240208	4	.072790	4	31	18 15-30/46
5		.184456	5	.112144	5	39	7 49-26/46
6		.134582	6	.158723	6	46	57 23-22/46
7		.091515	7	.211660	7	54	46 57-18/46
8		.056057	8	.269967	8	62	36 31-14/46
9		.028870	9	.332560	9	70	26 5-10/46
10		.010458	10	.398272	10	78	15 39- 6/46

# COORDINATE FACTORS AND ANGLES—46 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.001166	11	.465879	11	86	5 13- 2/46
12		.001166	12	.534121	12	93	54 46-44/46
13		.010458	13	.601728	13	101	44 20-40/46
14		.028870	14	.667440	14	109	33 54-36/46
15		.056057	15	.730033	15	117	23 28-32/46
16		.091515	16	.788340	16	125	13 2-28/46
17		.134582	17	.841277	17	133	2 36-24/46
18		.184456	18	.887856	18	140	52 10-20/46
19		.240208	19	.927210	19	148	41 44-16/46
20		.300803	20	.958606	20	156	31 18-12/46
21		.365102	21	.981459	21	164	20 52- 8/46
22		.431917	22	.995343	22	172	10 26- 4/46
23		.500000	23	1.000000	23	180	00 00000000
24		.568083	24	.995343	24	187	49 33-42/46
25		.634898	25	.981459	25	195	39 7-38/46
26		.699197	26	.958606	26	203	28 41-34/46
27		.759792	27	.927210	27	211	18 15-30/46
28		.815544	28	.887856	28	219	7 49-26/46
29		.865418	29	.841277	29	226	57 23-22/46
30		.908485	30	.788340	30	234	46 57-18/46
31		.943943	31	.730033	31	242	36 31-14/46
32		.971130	32	.667440	32	250	26 5-10/46
33		.989542	33	.601728	33	258	15 39- 6/46
34		.998834	34	.534121	34	266	5 13- 2/46
35		.998834	35	.465879	35	273	54 46-44/46
36		.989542	36	.398272	36	281	44 20-40/46
37		.971130	37	.332560	37	289	33 54-36/46
38		.943943	38	.269967	38	297	23 28-32/46
39		.908485	39	.211660	39	305	13 2-28/46
40		.865418	40	.158723	40	313	2 36-24/46
41		.815544	41	.112144	41	320	52 10-20/46
42		.759792	42	.072790	42	328	41 44-16/46
43		.699197	43	.041394	43	336	31 18-12/46
44		.634898	44	.018541	44	344	20 52- 8/46
45		.568083	45	.004657	45	352	10 26- 4/46
46		.500000	46	.000000	46	360	0 0

# 47 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

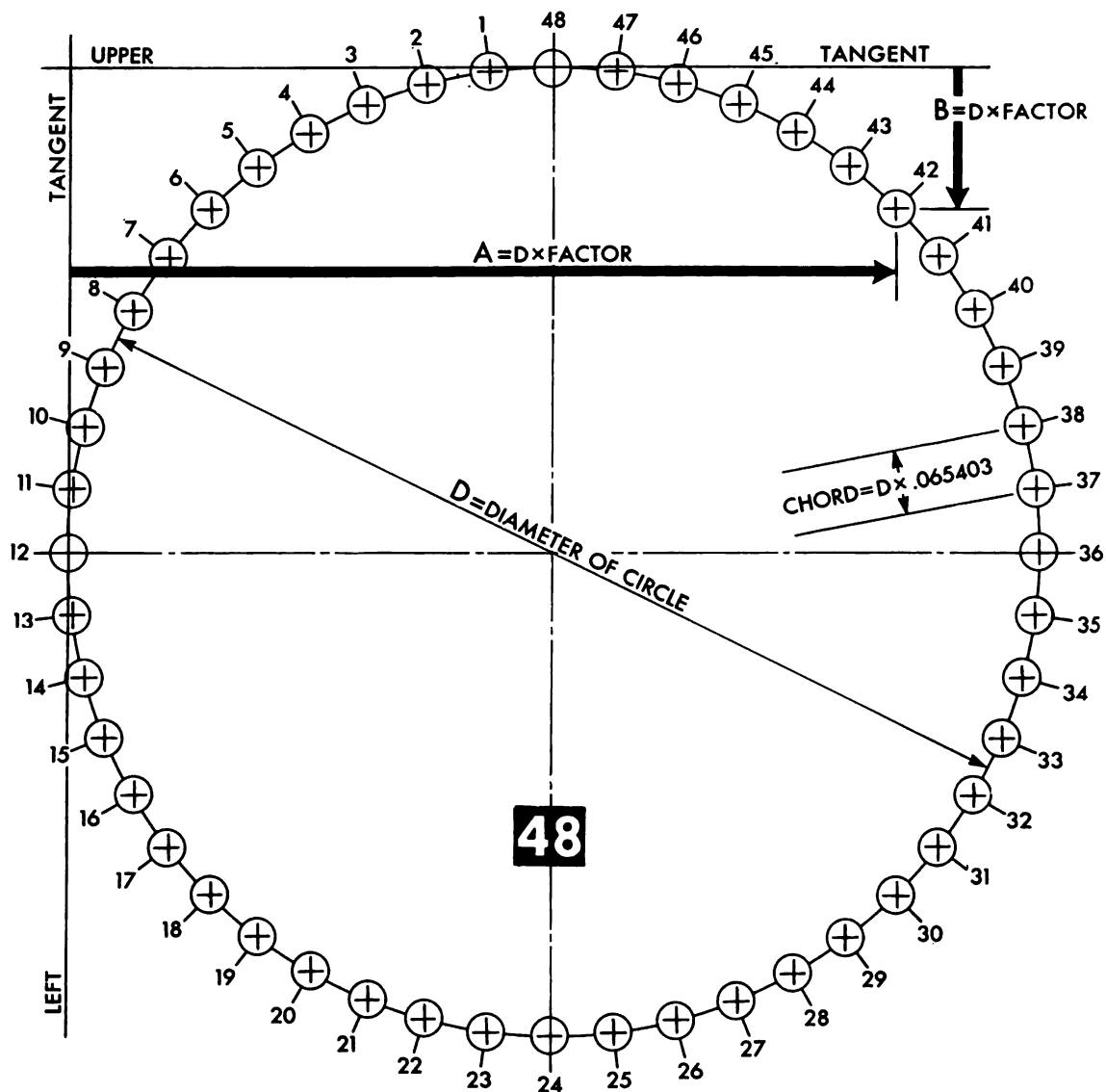


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.433357	1	.004461	1	7	39 34-22/47
2		.367902	2	.017765	2	15	19 8-44/47
3		.304806	3	.039675	3	22	58 43-19/47
4		.245192	4	.069799	4	30	38 17-41/47
5		.190125	5	.107600	5	38	17 52-16/47
6		.140588	6	.152404	6	45	57 26-38/47
7		.097465	7	.203410	7	53	37 1-13/47
8		.061525	8	.259709	8	61	16 35-35/47
9		.033410	9	.320296	9	68	56 10-10/47
10		.013621	10	.384090	10	76	35 44-32/47

# COORDINATE FACTORS AND ANGLES—47 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.002511	11	.449952	11	84	15 19- 7/47
12		.000279	12	.516707	12	91	54 53-29/47
13		.006965	13	.583165	13	99	34 28- 4/47
14		.022449	14	.648138	14	107	14 2-26/47
15		.046455	15	.710468	15	114	53 37- 1/47
16		.078554	16	.769041	16	122	33 11-23/47
17		.118174	17	.822814	17	130	12 45-45/47
18		.164608	18	.870826	18	137	52 20-20/47
19		.217026	19	.912221	19	145	31 54-42/47
20		.274495	20	.946259	20	153	11 29-17/47
21		.335988	21	.972335	21	160	51 3-39/47
22		.400407	22	.989981	22	168	30 38-14/47
23		.466604	23	.998883	23	176	10 12-36/47
24		.533396	24	.998883	24	183	49 47-11/47
25		.599593	25	.989981	25	191	29 21-33/47
26		.664012	26	.972335	26	199	8 56- 8/47
27		.725505	27	.946259	27	206	48 30-30/47
28		.782974	28	.912221	28	214	28 5- 5/47
29		.835392	29	.870826	29	222	7 39-27/47
30		.881826	30	.822814	30	229	47 14- 2/47
31		.921446	31	.769041	31	237	26 48-24/47
32		.953545	32	.710468	32	245	6 22-46/47
33		.977551	33	.648138	33	252	45 57-21/47
34		.993035	34	.583165	34	260	25 31-43/47
35		.999721	35	.516707	35	268	5 6-18/47
36		.997489	36	.449952	36	275	44 40-40/47
37		.986379	37	.384090	37	283	24 15-15/47
38		.966590	38	.320296	38	291	3 49-37/47
39		.938475	39	.259709	39	298	43 24-12/47
40		.902535	40	.203410	40	306	22 58-34/47
41		.859412	41	.152404	41	314	2 33- 9/47
42		.809875	42	.107600	42	321	42 7-31/47
43		.754808	43	.069799	43	329	21 42- 6/47
44		.695194	44	.039675	44	337	1 16-28/47
45		.632098	45	.017765	45	344	40 51- 3/47
46		.566643	46	.004461	46	352	20 25-25/47
47		.500000	47	.000000	47	360	0 0

# 48 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

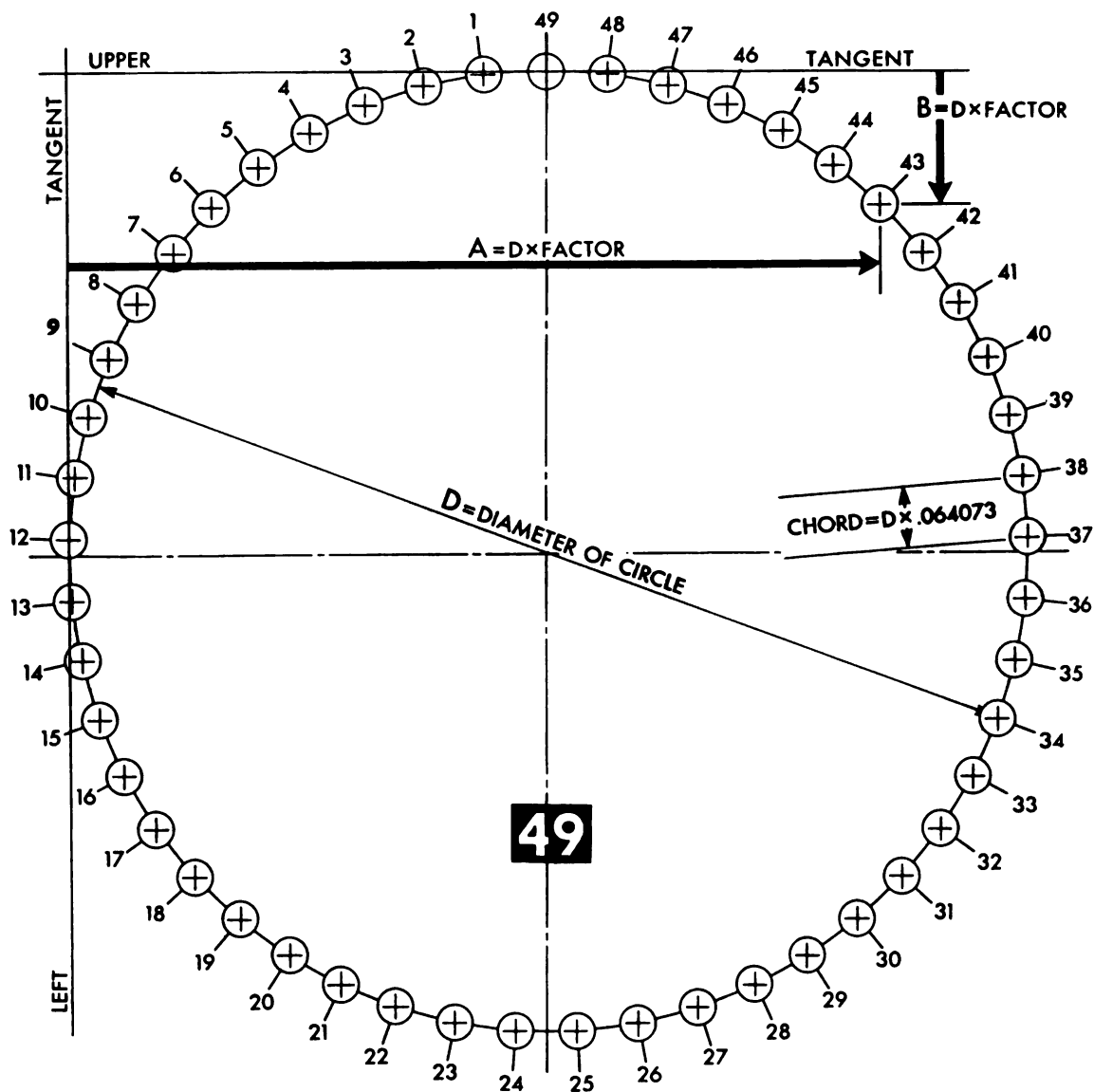


	➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.434737	1	.004278	1	7	30	0
2		.370590	2	.017037	2	15	00	0
3		.308658	3	.038060	3	22	30	0
4		.250000	4	.066987	4	30	00	0
5		.195619	5	.103323	5	37	30	0
6		.146447	6	.146447	6	45	00	0
7		.103323	7	.195619	7	52	30	0
8		.066987	8	.250000	8	60	00	0
9		.038060	9	.308658	9	67	30	0
10		.017037	10	.370590	10	75	00	0

# COORDINATE FACTORS AND ANGLES—48 HOLE DIVISION

	➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
11		.004278	11	.434737	11	82	30	0
12		.000000	12	.500000	12	90	00	0
13		.004278	13	.565263	13	97	30	0
14		.017037	14	.629410	14	105	00	0
15		.038060	15	.691342	15	112	30	0
16		.066987	16	.750000	16	120	00	0
17		.103323	17	.804381	17	127	30	0
18		.146447	18	.853553	18	135	00	0
19		.195619	19	.896677	19	142	30	0
20		.250000	20	.933013	20	150	00	0
21		.308658	21	.961940	21	157	30	0
22		.370590	22	.982963	22	165	00	0
23		.434737	23	.995722	23	172	30	0
24		.500000	24	1.000000	24	180	00	0
25		.565263	25	.995722	25	187	30	0
26		.629410	26	.982963	26	195	00	0
27		.691342	27	.961940	27	202	30	0
28		.750000	28	.933013	28	210	00	0
29		.804381	29	.896677	29	217	30	0
30		.853553	30	.853553	30	225	00	0
31		.896677	31	.804381	31	232	30	0
32		.933013	32	.750000	32	240	00	0
33		.961940	33	.691342	33	247	30	0
34		.982963	34	.629410	34	255	00	0
35		.995722	35	.565263	35	262	30	0
36		1.000000	36	.500000	36	270	00	0
37		.995722	37	.434737	37	277	30	0
38		.982963	38	.370590	38	285	00	0
39		.961940	39	.308658	39	292	30	0
40		.933013	40	.250000	40	300	00	0
41		.896677	41	.195619	41	307	30	0
42		.853553	42	.146447	42	315	00	0
43		.804381	43	.103323	43	322	30	0
44		.750000	44	.066987	44	330	00	0
45		.691342	45	.038060	45	337	30	0
46		.629410	46	.017037	46	345	00	0
47		.565263	47	.004278	47	352	30	0
48		.500000	48	.000000	48	360	0	0

# 49 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.436061	1	.004105	1	7	20 48-48/49
2		.373175	2	.016353	2	14	41 37-47/49
3		.312367	3	.036542	3	22	2 26-46/49
4		.254641	4	.064341	4	29	23 15-45/49
5		.200945	5	.099293	5	36	44 4-44/49
6		.152159	6	.140825	6	44	4 53-43/49
7		.109084	7	.188255	7	51	25 42-42/49
8		.072429	8	.240804	8	58	46 31-41/49
9		.042794	9	.297608	9	66	7 20-40/49
10		.020666	10	.357736	10	73	28 9-39/49

# COORDINATE FACTORS AND ANGLES—49 HOLE DIVISION

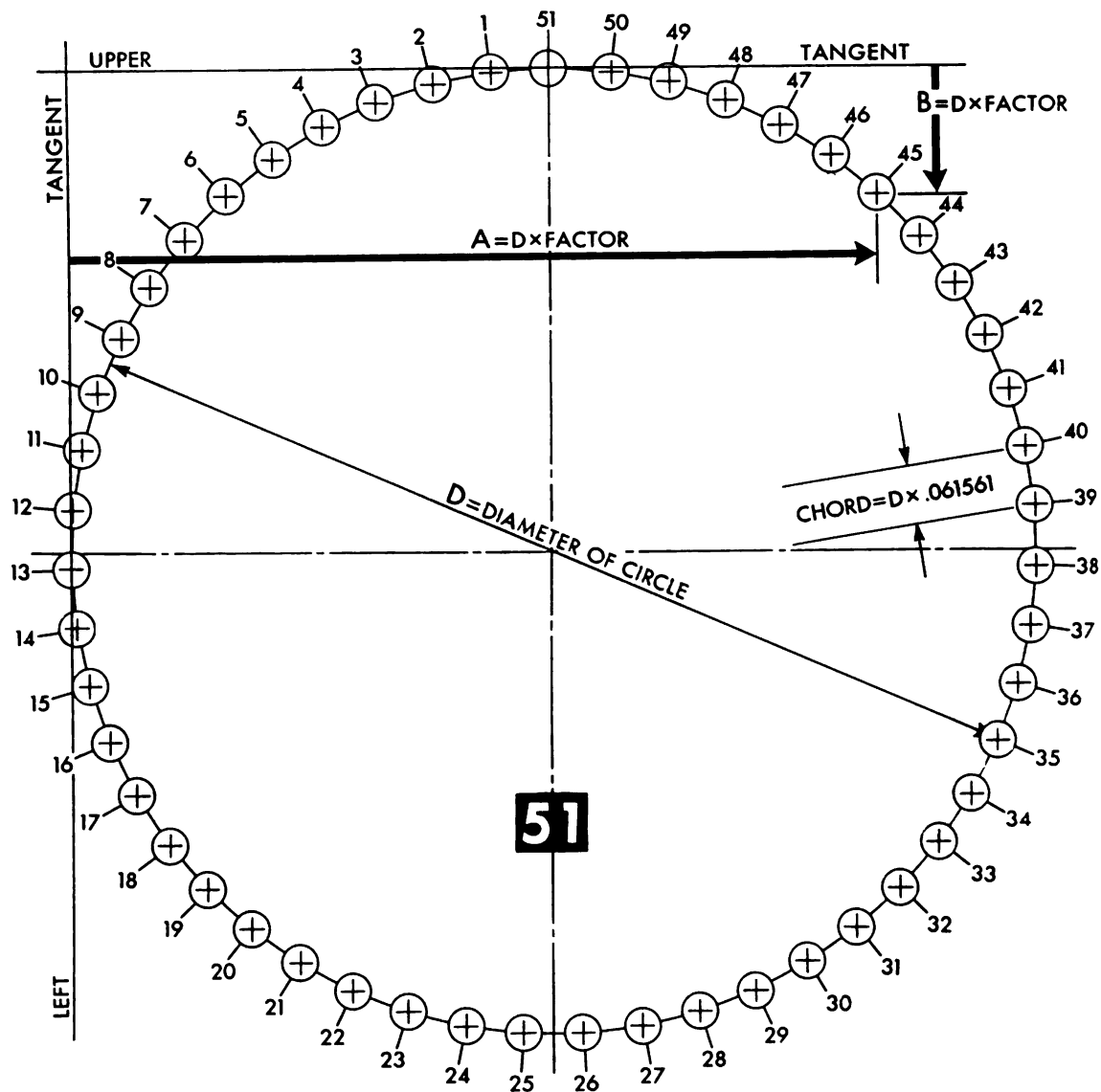
➔	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.006409	11	.420200	11	80	48	58-38/49
12	.000257	12	.483972	12	88	9	47-37/49
13	.002310	13	.548012	13	95	30	36-36/49
14	.012536	14	.611260	14	102	51	25-35/49
15	.030766	15	.672682	15	110	12	14-34/49
16	.056700	16	.731269	16	117	33	3-33/49
17	.089914	17	.786058	17	124	53	52-32/49
18	.129860	18	.836150	18	132	14	41-31/49
19	.175886	19	.880723	19	139	35	30-30/49
20	.227233	20	.919044	20	146	56	19-29/49
21	.283058	21	.950484	21	154	17	8-28/49
22	.342447	22	.974528	22	161	37	57-27/49
23	.404421	23	.990780	23	168	58	46-26/49
24	.467965	24	.998973	24	176	19	35-25/49
25	.532035	25	.998973	25	183	40	24-24/49
26	.595579	26	.990780	26	191	1	13-23/49
27	.657553	27	.974528	27	198	22	2-22/49
28	.716942	28	.950484	28	205	42	51-21/49
29	.772767	29	.919044	29	213	3	40-20/49
30	.824114	30	.880723	30	220	24	29-19/49
31	.870139	31	.836150	31	227	45	18-18/49
32	.910086	32	.786058	32	235	6	7-17/49
33	.943300	33	.731269	33	242	26	56-16/49
34	.969234	34	.672682	34	249	47	45-15/49
35	.987464	35	.611260	35	257	8	34-14/49
36	.997690	36	.548012	36	264	29	23-13/49
37	.999743	37	.483972	37	271	50	12-12/49
38	.993591	38	.420200	38	279	11	1-11/49
39	.979334	39	.357736	39	286	31	50-10/49
40	.957206	40	.297608	40	293	52	39- 9/49
41	.927571	41	.240804	41	301	13	28- 8/49
42	.890916	42	.188255	42	308	34	17- 7/49
43	.847841	43	.140825	43	315	55	6- 6/49
44	.799055	44	.099293	44	323	15	55- 5/49
45	.745359	45	.064341	45	330	36	44- 4/49
46	.687634	46	.036542	46	337	57	33- 3/49
47	.626825	47	.016353	47	345	18	22- 2/49
48	.563939	48	.004105	48	352	39	11- 1/49
49	.500000	49	.000000	49	360	0	0

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# COORDINATE FACTORS AND ANGLES—50 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.008856	11	.406309	11	79	12	0
12	.000987	12	.468605	12	86	24	0
13	.000987	13	.531395	13	93	36	0
14	.008856	14	.593691	14	100	48	0
15	.024472	15	.654508	15	108	00	0
16	.047586	16	.712890	16	115	12	0
17	.077836	17	.767913	17	122	24	0
18	.114743	18	.818712	18	129	36	0
19	.157726	19	.864484	19	136	48	0
20	.206107	20	.904508	20	144	00	0
21	.259123	21	.938153	21	151	12	0
22	.315937	22	.964888	22	158	24	0
23	.375655	23	.984292	23	165	36	0
24	.437333	24	.996057	24	172	48	0
25	.500000	25	1.000000	25	180	00	0
26	.562667	26	.996057	26	187	12	0
27	.624345	27	.984292	27	194	24	0
28	.684062	28	.964888	28	201	36	0
29	.740877	29	.938153	29	208	48	0
30	.793893	30	.904508	30	216	00	0
31	.842274	31	.864484	31	223	12	0
32	.885257	32	.818712	32	230	24	0
33	.922164	33	.767913	33	237	36	0
34	.952414	34	.712890	34	244	48	0
35	.975528	35	.654508	35	252	00	0
36	.991144	36	.593691	36	259	12	0
37	.999013	37	.531395	37	266	24	0
38	.999013	38	.468605	38	273	36	0
39	.991144	39	.406309	39	280	48	0
40	.975528	40	.345492	40	288	00	0
41	.952414	41	.287110	41	295	12	0
42	.922164	42	.232087	42	302	24	0
43	.885257	43	.181288	43	309	36	0
44	.842274	44	.135516	44	316	48	0
45	.793893	45	.095492	45	324	00	0
46	.740877	46	.061847	46	331	12	0
47	.684062	47	.035112	47	338	24	0
48	.624345	48	.015708	48	345	36	0
49	.562667	49	.003943	49	352	48	0
50	.500000	50	.000000	50	360	0	0

# 51 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

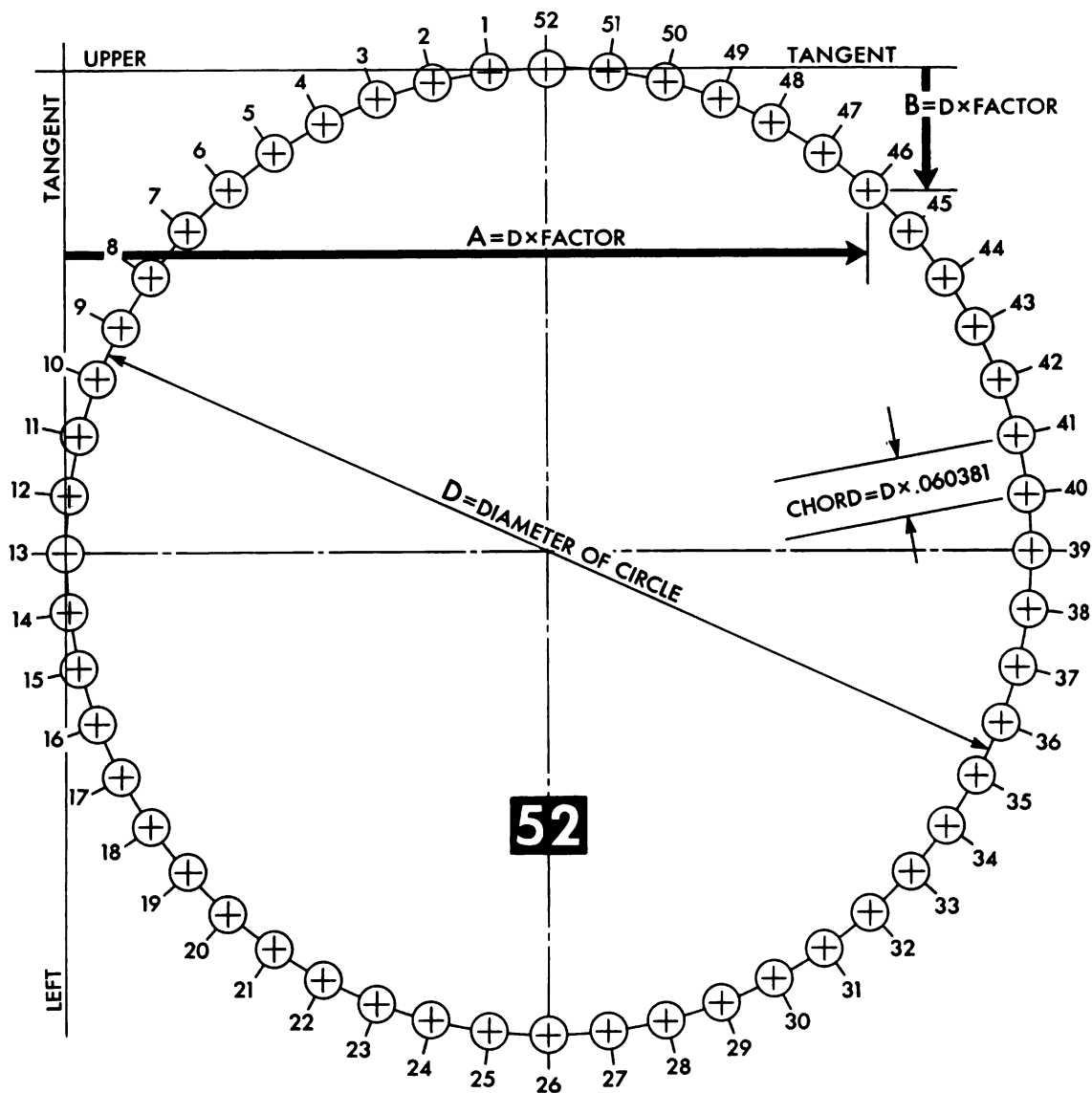


➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.438556	1	.003790	1	7	31-39 51
2	.378043	2	.015102	2	14	3-27 51
3	.319379	3	.033764	3	21	35-15 51
4	.263453	4	.059494	4	28	7- 3 51
5	.211113	5	.091901	5	35	38-42 51
6	.163152	6	.130496	6	42	10-30 51
7	.120298	7	.174691	7	49	42-18 51
8	.083199	8	.223817	8	56	14- 6 51
9	.052418	9	.277131	9	63	45-45 51
10	.028423	10	.333823	10	70	17-33 51

# COORDINATE FACTORS AND ANGLES—51 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11		.011576	11	.393034	11	77	38 49-21/51
12		.002133	12	.453866	12	84	42 21- 9/51
13		.000237	13	.515398	13	91	45 52-48/51
14		.005917	14	.576696	14	98	49 24-36/51
15		.019087	15	.636832	15	105	52 56-24/51
16		.039547	16	.694893	16	112	56 28-12/51
17		.066987	17	.750000	17	120	00 00000000
18		.100991	18	.801317	18	127	3 31-39/51
19		.141044	19	.848067	19	134	7 3-27/51
20		.186538	20	.889540	20	141	10 35-15/51
21		.236784	21	.925109	21	148	14 7- 3/51
22		.291020	22	.954233	22	155	17 38-42/51
23		.348423	23	.976471	23	162	21 10-30/51
24		.408125	24	.991487	24	169	24 42-18/51
25		.469220	25	.999052	25	176	28 14- 6/51
26		.530780	26	.999052	26	183	31 45-45/51
27		.591875	27	.991487	27	190	35 17-33/51
28		.651577	28	.976471	28	197	38 49-21/51
29		.708980	29	.954233	29	204	42 21- 9/51
30		.763216	30	.925109	30	211	45 52-48/51
31		.813462	31	.889540	31	218	49 24-36/51
32		.858956	32	.848067	32	225	52 56-24/51
33		.899009	33	.801317	33	232	56 28-12/51
34		.933013	34	.750000	34	240	00 00000000
35		.960453	35	.694893	35	247	3 31-39/51
36		.980913	36	.636832	36	254	7 3-27/51
37		.994083	37	.576696	37	261	10 35-15/51
38		.999763	38	.515398	38	268	14 7- 3/51
39		.997867	39	.453866	39	275	17 38-42/51
40		.988424	40	.393034	40	282	21 10-30/51
41		.971577	41	.333823	41	289	24 42-18/51
42		.947582	42	.277131	42	296	28 14- 6/51
43		.916801	43	.223817	43	303	31 45-45/51
44		.879702	44	.174691	44	310	35 17-33/51
45		.836847	45	.130496	45	317	38 49-21/51
46		.788887	46	.091901	46	324	42 21- 9/51
47		.736547	47	.059494	47	331	45 52-48/51
48		.680621	48	.033764	48	338	49 24-36/51
49		.621957	49	.015102	49	345	52 56-24/51
50		.561444	50	.003790	50	352	56 28-12/51
51		.500000	51	.000000	51	360	0 0

## 52 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

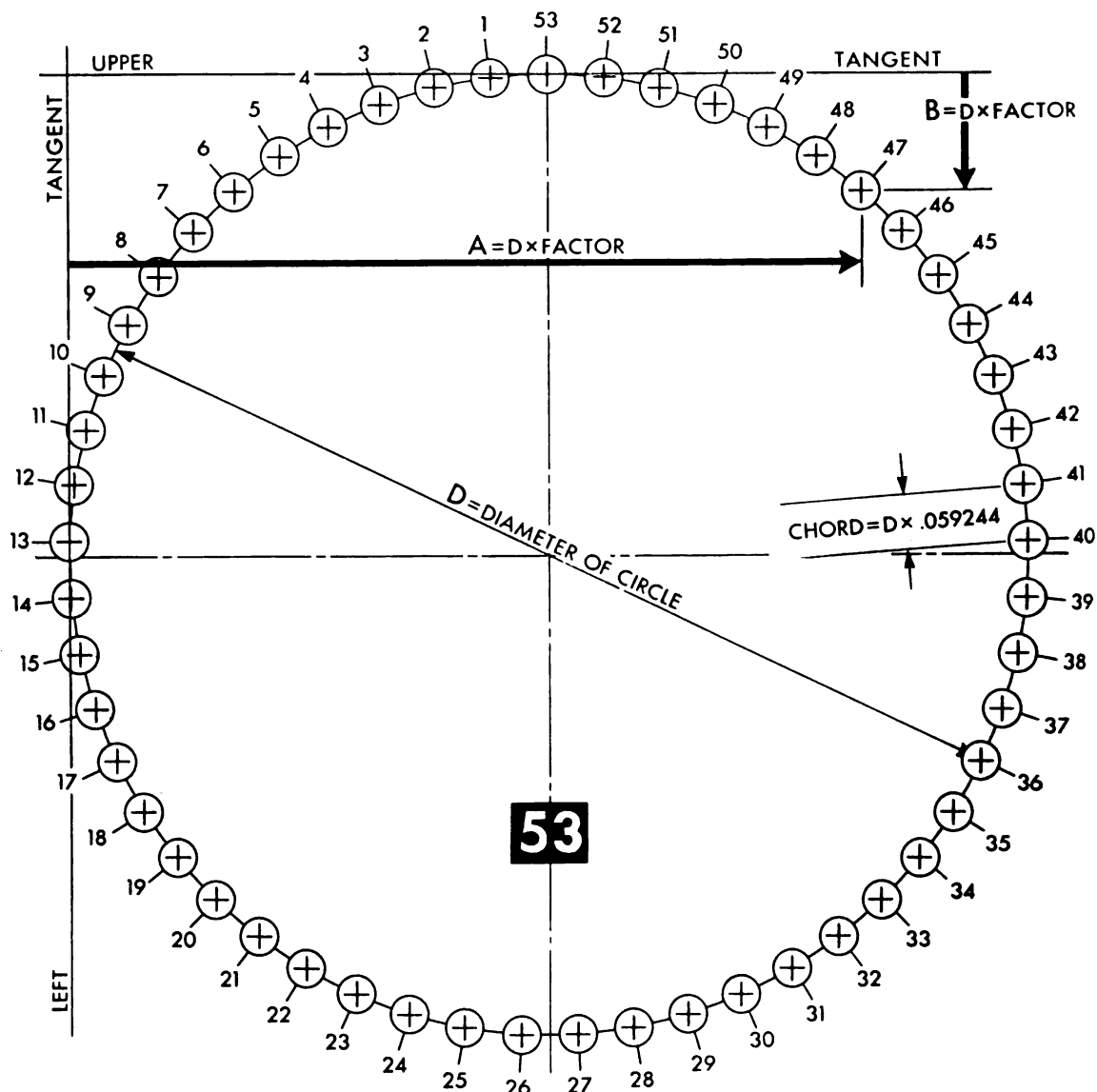


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.439732	1	.003646	1	6	55	23- 4/52
2	.380342	2	.014529	2	13	50	46- 8/52
3	.322698	3	.032492	3	20	46	9-12/52
4	.267638	4	.057272	4	27	41	32-16/52
5	.215968	5	.088508	5	34	36	55-20/52
6	.168439	6	.125745	6	41	32	18-24/52
7	.125745	7	.168439	7	48	27	41-28/52
8	.088508	8	.215968	8	55	23	4-32/52
9	.057272	9	.267638	9	62	18	27-36/52
10	.032492	10	.322698	10	69	13	50-40/52
11	.014529	11	.380342	11	76	9	13-44/52

# COORDINATE FACTORS AND ANGLES—52 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.003646	12	.439732	12	83	4 36-48/52
13	.000000	13	.500000	13	90	00 00000000
14	.003646	14	.560268	14	96	55 23- 4/52
15	.014529	15	.619658	15	103	50 46- 8/52
16	.032492	16	.677302	16	110	46 9-12/52
17	.057272	17	.732362	17	117	41 32-16/52
18	.088508	18	.784032	18	124	36 55-20/52
19	.125745	19	.831561	19	131	32 18-24/52
20	.168439	20	.874255	20	138	27 41-28/52
21	.215968	21	.911492	21	145	23 4-32/52
22	.267638	22	.942728	22	152	18 27-36/52
23	.322698	23	.967508	23	159	13 50-40/52
24	.380342	24	.985471	24	166	9 13-44/52
25	.439732	25	.996354	25	173	4 36-48/52
26	.500000	26	1.000000	26	180	00 00000000
27	.560268	27	.996354	27	186	55 23- 4/52
28	.619658	28	.985471	28	193	50 46- 8/52
29	.677302	29	.967508	29	200	46 9-12/52
30	.732362	30	.942728	30	207	41 32-16/52
31	.784032	31	.911492	31	214	36 55-20/52
32	.831561	32	.874255	32	221	32 18-24/52
33	.874255	33	.831561	33	228	27 41-28/52
34	.911492	34	.784032	34	235	23 4-32/52
35	.942728	35	.732362	35	242	18 27-36/52
36	.967508	36	.677302	36	249	13 50-40/52
37	.985471	37	.619658	37	256	9 13-44/52
38	.996354	38	.560268	38	263	4 36-48/52
39	1.000000	39	.500000	39	270	00 00000000
40	.996354	40	.439732	40	276	55 23- 4/52
41	.985471	41	.380342	41	283	50 46- 8/52
42	.967508	42	.322698	42	290	46 9-12/52
43	.942728	43	.267638	43	297	41 32-16/52
44	.911492	44	.215968	44	304	36 55-20/52
45	.874255	45	.168439	45	311	32 18-24/52
46	.831561	46	.125745	46	318	27 41-28/52
47	.784032	47	.088508	47	325	23 4-32/52
48	.732362	48	.057272	48	332	18 27-36/52
49	.677302	49	.032492	49	339	13 50-40/52
50	.619658	50	.014529	50	346	9 13-44/52
51	.560268	51	.003646	51	353	4 36-48/52
52	.500000	52	.000000	52	360	0 0

# 53 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

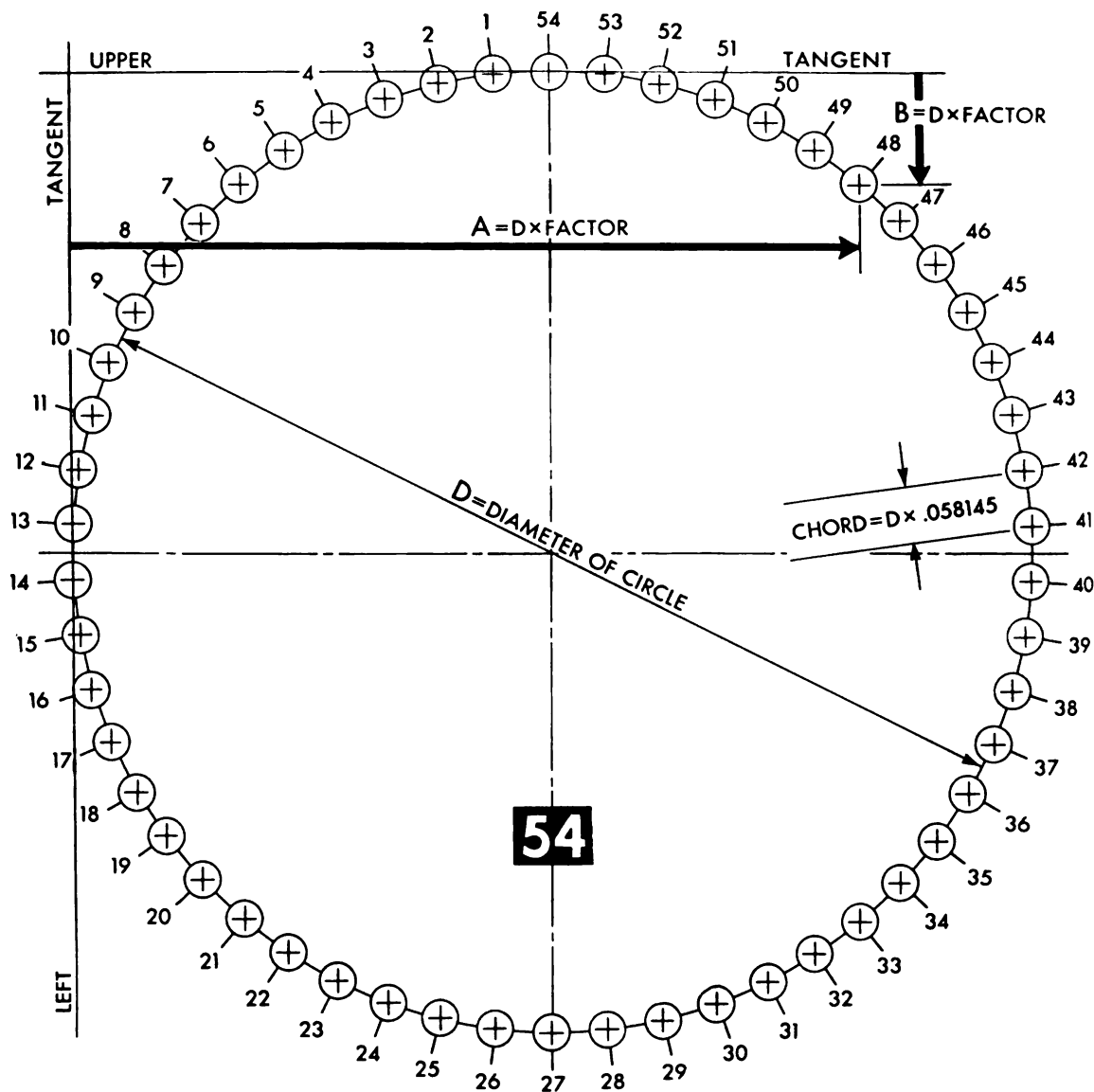


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.440863	1	.003510	1	6	47 32-44/53
2		.382557	2	.013989	2	13	35 5-35/53
3		.325899	3	.031290	3	20	22 38-26/53
4		.271685	4	.055172	4	27	10 11-17/53
5		.220677	5	.085299	5	33	57 44- 8/53
6		.173590	6	.121244	6	40	45 16-52/53
7		.131083	7	.162509	7	47	32 49-43/53
8		.093757	8	.208510	8	54	20 22-34/53
9		.062133	9	.258603	9	61	7 55-25/53
10		.036655	10	.312086	10	67	55 28-16/53
11		.017682	11	.368206	11	74	43 1- 7/53

# COORDINATE FACTORS AND ANGLES—53 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
12		.005480	12	.426177	12	81	30 33-51/53
13		.000220	13	.485183	13	88	18 6-42/53
14		.001975	14	.544398	14	95	5 39-33/53
15		.010722	15	.602990	15	101	53 12-24/53
16		.026337	16	.660135	16	108	40 45-15/53
17		.048601	17	.715033	17	115	28 18- 6/53
18		.077202	18	.766912	18	122	15 50-50/53
19		.111738	19	.815044	19	129	3 23-41/53
20		.151725	20	.858754	20	135	50 56-32/53
21		.196600	21	.897427	21	142	38 29-23/53
22		.245734	22	.930522	22	149	26 2-14/53
23		.298438	23	.957573	23	156	13 35- 5/53
24		.353972	24	.978201	24	163	1 7-49/53
25		.411555	25	.992115	25	169	48 40-40/53
26		.470380	26	.999122	26	176	36 13-31/53
27		.529620	27	.999122	27	183	23 46-22/53
28		.588445	28	.992115	28	190	11 19-13/53
29		.646028	29	.978201	29	196	58 52- 4/53
30		.701562	30	.957573	30	203	46 24-48/53
31		.754266	31	.930522	31	210	33 57-39/53
32		.803400	32	.897427	32	217	21 30-30/53
33		.848276	33	.858754	33	224	9 3-21/53
34		.888262	34	.815044	34	230	56 36-12/53
35		.922798	35	.766912	35	237	44 9- 3/53
36		.951399	36	.715033	36	244	31 41-47/53
37		.973663	37	.660135	37	251	19 14-38/53
38		.989278	38	.602990	38	258	6 47-29/53
39		.998025	39	.544398	39	264	54 20-20/53
40		.999780	40	.485183	40	271	41 53-11/53
41		.994520	41	.426177	41	278	29 26- 2/53
42		.982318	42	.368206	42	285	16 58-46/53
43		.963345	43	.312086	43	292	4 31-37/53
44		.937868	44	.258603	44	298	52 4-28/53
45		.906243	45	.208510	45	305	39 37-19/53
46		.868917	46	.162509	46	312	27 10-10/53
47		.826410	47	.121244	47	319	14 43- 1/53
48		.779323	48	.085299	48	326	2 15-45/53
49		.728315	49	.055172	49	332	49 48-36/53
50		.674101	50	.031290	50	339	37 21-27/53
51		.617443	51	.013989	51	346	24 54-18/53
52		.559137	52	.003510	52	353	12 27- 9/53
53		.500000	53	.000000	53	360	0 0

# 54 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

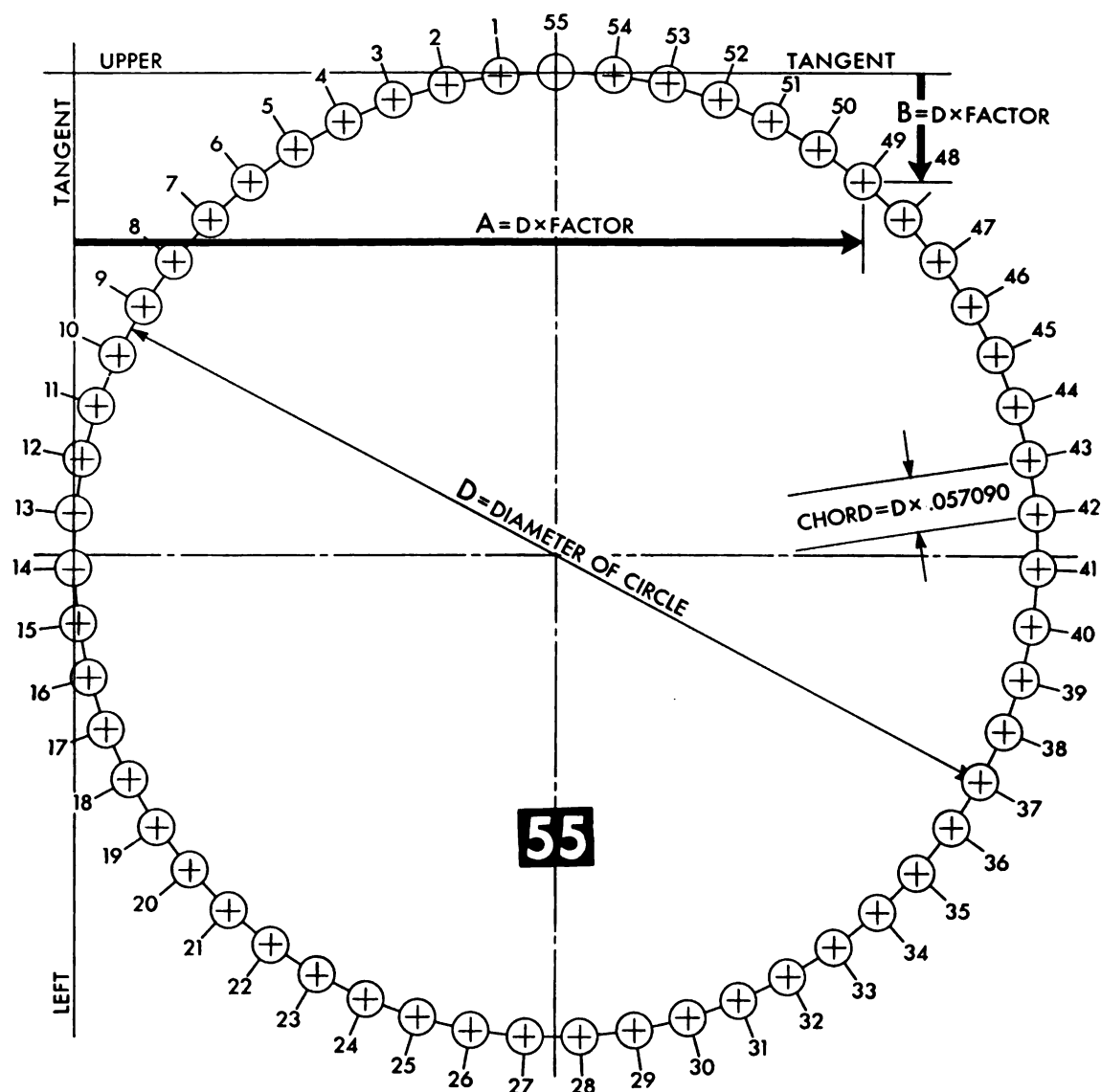


➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
1	.441954	1	.003381	1	6	40	0
2	.384692	2	.013478	2	13	20	0
3	.328990	3	.030154	3	20	00	0
4	.275600	4	.053184	4	26	40	0
5	.225246	5	.082256	5	33	20	0
6	.178606	6	.116978	6	40	00	0
7	.136313	7	.156879	7	46	40	0
8	.098938	8	.201421	8	53	20	0
9	.066987	9	.250000	9	60	00	0
10	.040892	10	.301960	10	66	40	0
11	.021005	11	.356598	11	73	20	0

# COORDINATE FACTORS AND ANGLES—54 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
12	.007596	12	.413176	12	80	00	0
13	.000846	13	.470928	13	86	40	0
14	.000846	14	.529072	14	93	20	0
15	.007596	15	.586824	15	100	00	0
16	.021005	16	.643402	16	106	40	0
17	.040892	17	.698040	17	113	20	0
18	.066987	18	.750000	18	120	00	0
19	.098938	19	.798579	19	126	40	0
20	.136313	20	.843121	20	133	20	0
21	.178606	21	.883022	21	140	00	0
22	.225246	22	.917744	22	146	40	0
23	.275600	23	.946816	23	153	20	0
24	.328990	24	.969846	24	160	00	0
25	.384692	25	.986522	25	166	40	0
26	.441954	26	.996619	26	173	20	0
27	.500000	27	1.000000	27	180	00	0
28	.558046	28	.996619	28	186	40	0
29	.615308	29	.986522	29	193	20	0
30	.671010	30	.969846	30	200	00	0
31	.724400	31	.946816	31	206	40	0
32	.774755	32	.917744	32	213	20	0
33	.821394	33	.883022	33	220	00	0
34	.863687	34	.843121	34	226	40	0
35	.901062	35	.798579	35	233	20	0
36	.933013	36	.750000	36	240	00	0
37	.959108	37	.698040	37	246	40	0
38	.978995	38	.643402	38	253	20	0
39	.992404	39	.586824	39	260	00	0
40	.999154	40	.529072	40	266	40	0
41	.999154	41	.470928	41	273	20	0
42	.992404	42	.413176	42	280	00	0
43	.978995	43	.356598	43	286	40	0
44	.959108	44	.301960	44	293	20	0
45	.933013	45	.250000	45	300	00	0
46	.901062	46	.201421	46	306	40	0
47	.863687	47	.156879	47	313	20	0
48	.821394	48	.116978	48	320	00	0
49	.774755	49	.082256	49	326	40	0
50	.724400	50	.053184	50	333	20	0
51	.671010	51	.030154	51	340	00	0
52	.615308	52	.013478	52	346	40	0
53	.558046	53	.003381	53	353	20	0
54	.500000	54	.000000	54	360	0	0

# 55 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

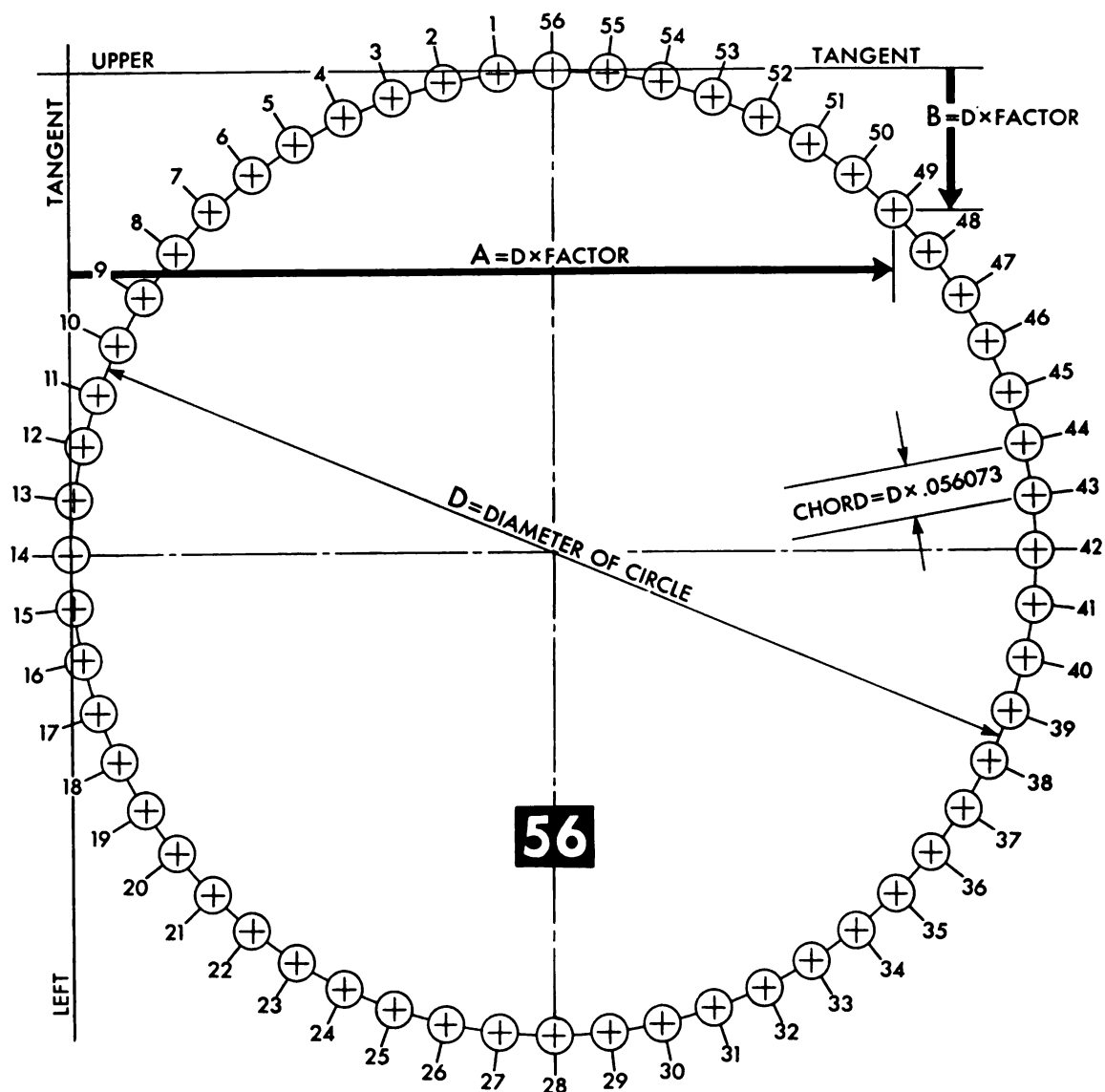


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.443004	1	.003259	1	6	32 43-35/55
2		.386752	2	.012994	2	13	5 27-15/55
3		.331975	3	.029078	3	19	38 10-50/55
4		.279389	4	.051301	4	26	10 54-30/55
5		.229680	5	.079373	5	32	43 38-10/55
6		.183494	6	.112929	6	39	16 21-45/55
7		.141434	7	.151531	7	45	49 5-25/55
8		.104049	8	.194678	8	52	21 49- 5/55
9		.071826	9	.241801	9	58	54 32-40/55
10		.045184	10	.292293	10	65	27 16-20/55
11		.024472	11	.345492	11	72	00 0000000

# COORDINATE FACTORS AND ANGLES—55 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.009957	12	.400705	12	78	32 43-35/55
13	.001834	13	.457213	13	85	5 27-15/55
14	.000204	14	.514278	14	91	38 10-50/55
15	.005089	15	.571157	15	98	10 54-30/55
16	.016427	16	.627109	16	104	43 38-10/55
17	.034068	17	.681404	17	111	16 21-45/55
18	.057784	18	.733334	18	117	49 5-25/55
19	.087264	19	.782222	19	124	21 49- 5/55
20	.122125	20	.827430	20	130	54 32-40/55
21	.161913	21	.868371	21	137	27 16-20/55
22	.206107	22	.904509	22	144	00 00000000
23	.254134	23	.935373	23	150	32 43-35/55
24	.305365	24	.960562	24	157	5 27-15/55
25	.359134	25	.979747	25	163	38 10-50/55
26	.414739	26	.992677	26	170	10 54-30/55
27	.471456	27	.999185	27	176	43 38-10/55
28	.528544	28	.999185	28	183	16 21-45/55
29	.585261	29	.992677	29	189	49 5-25/55
30	.640866	30	.979747	30	196	21 49- 5/55
31	.694635	31	.960562	31	202	54 32-40/55
32	.745867	32	.935373	32	209	27 16-20/55
33	.793893	33	.904509	33	216	00 00000000
34	.838087	34	.868371	34	222	32 43-35/55
35	.877875	35	.827430	35	229	5 27-15/55
36	.912736	36	.782222	36	235	38 10-50/55
37	.942217	37	.733334	37	242	10 54-30/55
38	.965932	38	.681404	38	248	43 38-10/55
39	.983573	39	.627109	39	255	16 21-45/55
40	.994911	40	.571157	40	261	49 5-25/55
41	.999796	41	.514278	41	268	21 49- 5/55
42	.998166	42	.457213	42	274	54 32-40/55
43	.990041	43	.400705	43	281	27 16-20/55
44	.975528	44	.345492	44	288	00 00000000
45	.954816	45	.292293	45	294	32 43-35/55
46	.928175	46	.241801	46	301	5 27-15/55
47	.895951	47	.194678	47	307	38 10-50/55
48	.858566	48	.151531	48	314	10 54-30/55
49	.816506	49	.112929	49	320	43 38-10/55
50	.770321	50	.079373	50	327	16 21-45/55
51	.720611	51	.051301	51	333	49 5-25/55
52	.668025	52	.029078	52	340	21 49- 5/55
53	.613249	53	.012994	53	346	54 32-40/55
54	.556996	54	.003259	54	353	27 16-20/55
55	.500000	55	.000000	55	360	0 0

# 56 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

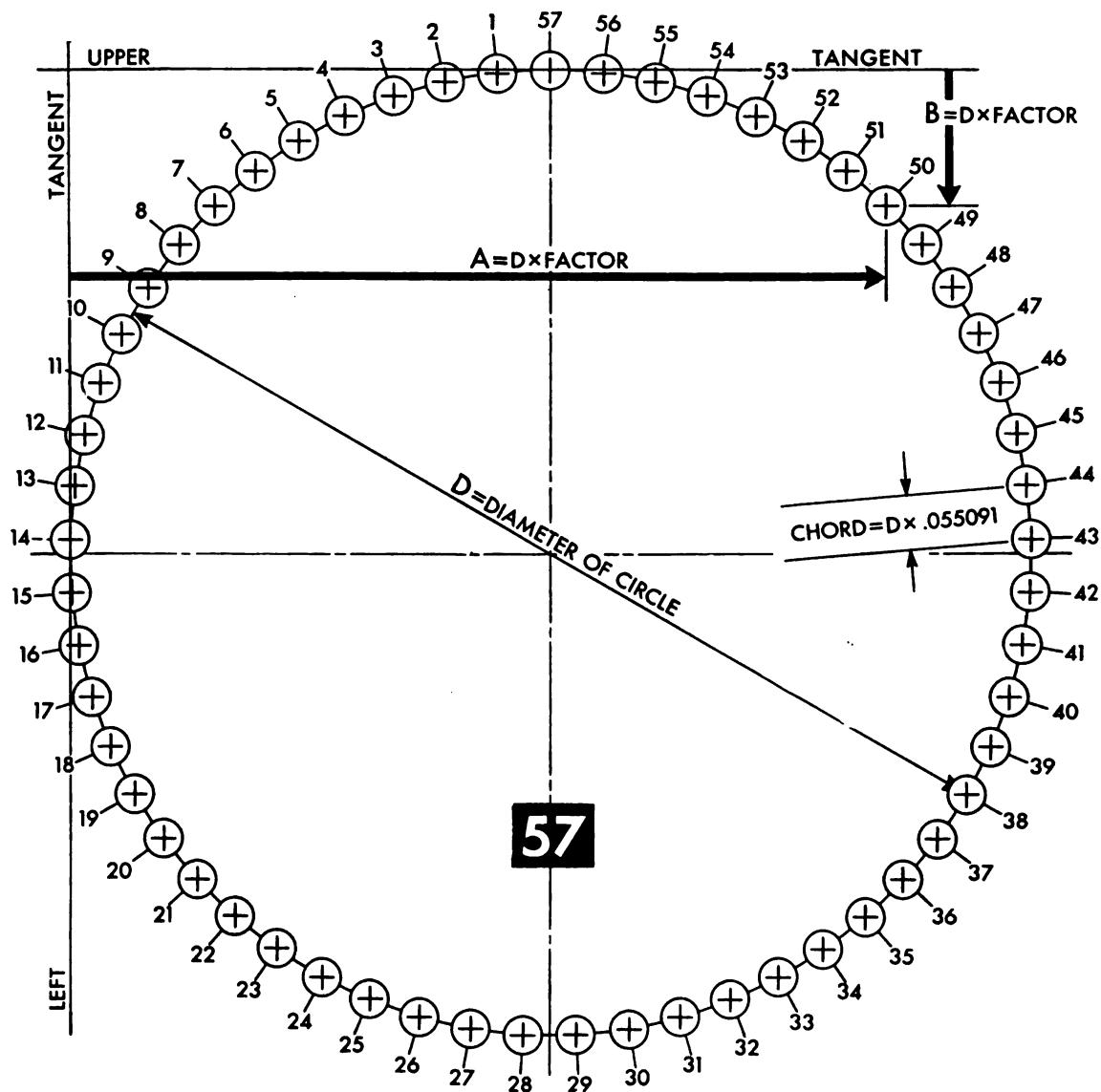


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.444018	1	.003144	1	6	25 42-48/56
2		.388740	2	.012536	2	12	51 25-40/56
3		.334861	3	.028058	3	19	17 8-32/56
4		.283058	4	.049516	4	25	42 51-24/56
5		.233984	5	.076638	5	32	8 34-16/56
6		.188255	6	.109084	6	38	34 17- 8/56
7		.146447	7	.146447	7	45	00 00000000
8		.109084	8	.188255	8	51	25 42-48/56
9		.076638	9	.233984	9	57	51 25-40/56
10		.049516	10	.283058	10	64	17 8-32/56
11		.028058	11	.334861	11	70	42 51-24/56

# COORDINATE FACTORS AND ANGLES—56 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
12	.012536	12	.388740	12	77	8	34-16/56
13	.003144	13	.444018	13	83	34	17- 8/56
14	.000000	14	.500000	14	90	00	00000000
15	.003144	15	.555982	15	96	25	42-48/56
16	.012536	16	.611261	16	102	51	25-40/56
17	.028058	17	.665140	17	109	17	8-32/56
18	.049516	18	.716942	18	115	42	51-24/56
19	.076638	19	.766016	19	122	8	34-16/56
20	.109084	20	.811745	20	128	34	17- 8/56
21	.146447	21	.853553	21	135	00	00000000
22	.188255	22	.890916	22	141	25	42-48/56
23	.233984	23	.923362	23	147	51	25-40/56
24	.283058	24	.950484	24	154	17	8-32/56
25	.334861	25	.971942	25	160	42	51-24/56
26	.388740	26	.987464	26	167	8	34-16/56
27	.444018	27	.996856	27	173	34	17- 8/56
28	.500000	28	1.000000	28	180	00	00000000
29	.555982	29	.996856	29	186	25	42-48/56
30	.611261	30	.987464	30	192	51	25-40/56
31	.665140	31	.971942	31	199	17	8-32/56
32	.716942	32	.950484	32	205	42	51-24/56
33	.766016	33	.923362	33	212	8	34-16/56
34	.811745	34	.890916	34	218	34	17- 8/56
35	.853553	35	.853553	35	225	00	00000000
36	.890916	36	.811745	36	231	25	42-48/56
37	.923362	37	.766016	37	237	51	25-40/56
38	.950484	38	.716942	38	244	17	8-32/56
39	.971942	39	.665140	39	250	42	51-24/56
40	.987464	40	.611261	40	257	8	34-16/56
41	.996856	41	.555982	41	263	34	17- 8/56
42	1.000000	42	.500000	42	270	00	00000000
43	.996856	43	.444018	43	276	25	42-48/56
44	.987464	44	.388740	44	282	51	25-40/56
45	.971942	45	.334861	45	289	17	8-32/56
46	.950484	46	.283058	46	295	42	51-24/56
47	.923362	47	.233984	47	302	8	34-16/56
48	.890916	48	.188255	48	308	34	17- 8/56
49	.853553	49	.146447	49	315	00	00000000
50	.811745	50	.109084	50	321	25	42-48/56
51	.766016	51	.076638	51	327	51	25-40/56
52	.716942	52	.049516	52	334	17	8-32/56
53	.665140	53	.028058	53	340	42	51-24/56
54	.611261	54	.012536	54	347	8	34-16/56
55	.555982	55	.003144	55	353	34	17- 8/56
56	.500000	56	.000000	56	360	0	0

# 57 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

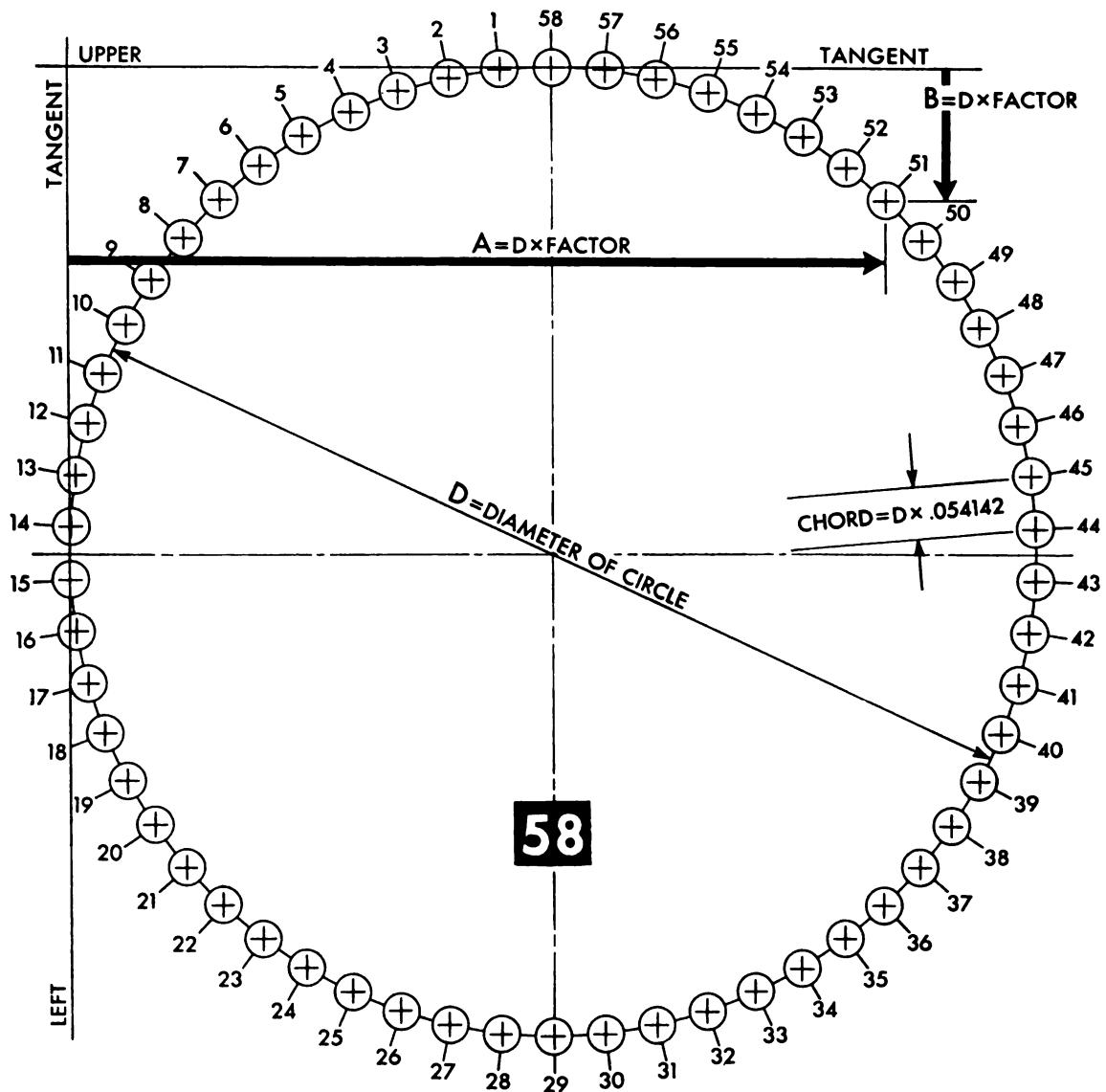


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.444996	1	.003035	1	6	18 56-48/57
2	.390660	2	.012102	2	12	37 53-39/57
3	.337650	3	.027091	3	18	56 50-30/57
4	.286612	4	.047822	4	25	15 47-21/57
5	.238164	5	.074040	5	31	34 44-12/57
6	.192894	6	.105430	6	37	53 41- 3/57
7	.151352	7	.141609	7	44	12 37-51/57
8	.114042	8	.182138	8	50	31 34-42/57
9	.081417	9	.226526	9	56	50 31-33/57
10	.053873	10	.274233	10	63	9 28-24/57
11	.031744	11	.324681	11	69	28 25-15/57

# COORDINATE FACTORS AND ANGLES—57 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.015300	12	.377257	12	75	47 22- 6/57
13	.004739	13	.431323	13	82	6 18-54/57
14	.000190	14	.486223	14	88	25 15-45/57
15	.001708	15	.541290	15	94	44 12-36/57
16	.009274	16	.595855	16	101	3 9-27/57
17	.022798	17	.649257	17	107	22 6-18/57
18	.042113	18	.700848	18	113	41 3- 9/57
19	.066987	19	.750000	19	120	00 00000000
20	.097118	20	.796118	20	126	18 56-48/57
21	.132138	21	.838641	21	132	37 53-39/57
22	.171624	22	.877054	22	138	56 50-30/57
23	.215096	23	.910889	23	145	15 47-21/57
24	.262026	24	.939737	24	151	34 44-12/57
25	.311845	25	.963247	25	157	53 41- 3/57
26	.363948	26	.981134	26	164	12 37-51/57
27	.417703	27	.993181	27	170	31 34-42/57
28	.472456	28	.999241	28	176	50 31-33/57
29	.527544	29	.999241	29	183	9 28-24/57
30	.582297	30	.993181	30	189	28 25-15/57
31	.636052	31	.981134	31	195	47 22- 6/57
32	.688155	32	.963247	32	202	6 18-54/57
33	.737974	33	.939737	33	208	25 15-45/57
34	.784904	34	.910889	34	214	44 12-36/57
35	.828376	35	.877054	35	221	3 9-27/57
36	.867862	36	.838641	36	227	22 6-18/57
37	.902883	37	.796118	37	233	41 3- 9/57
38	.933013	38	.750000	38	240	00 00000000
39	.957887	39	.700848	39	246	18 56-48/57
40	.977203	40	.649257	40	252	37 53-39/57
41	.990726	41	.595855	41	258	56 50-30/57
42	.998292	42	.541290	42	265	15 47-21/57
43	.999810	43	.486223	43	271	34 44-12/57
44	.995261	44	.431323	44	277	53 41- 3/57
45	.984700	45	.377257	45	284	12 37-51/57
46	.968256	46	.324681	46	290	31 34-42/57
47	.946127	47	.274233	47	296	50 31-33/57
48	.918583	48	.226526	48	303	9 28-24/57
49	.885958	49	.182138	49	309	28 25-15/57
50	.848648	50	.141609	50	315	47 22- 6/57
51	.807106	51	.105430	51	322	6 18-54/57
52	.761837	52	.074040	52	328	25 15-45/57
53	.713388	53	.047822	53	334	44 12-36/57
54	.662350	54	.027091	54	341	3 9-27/57
55	.609340	55	.012102	55	347	22 6-18/57
56	.555004	56	.003035	56	353	41 3- 9/57
57	.500000	57	.000000	57	360	0 0

# 58 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

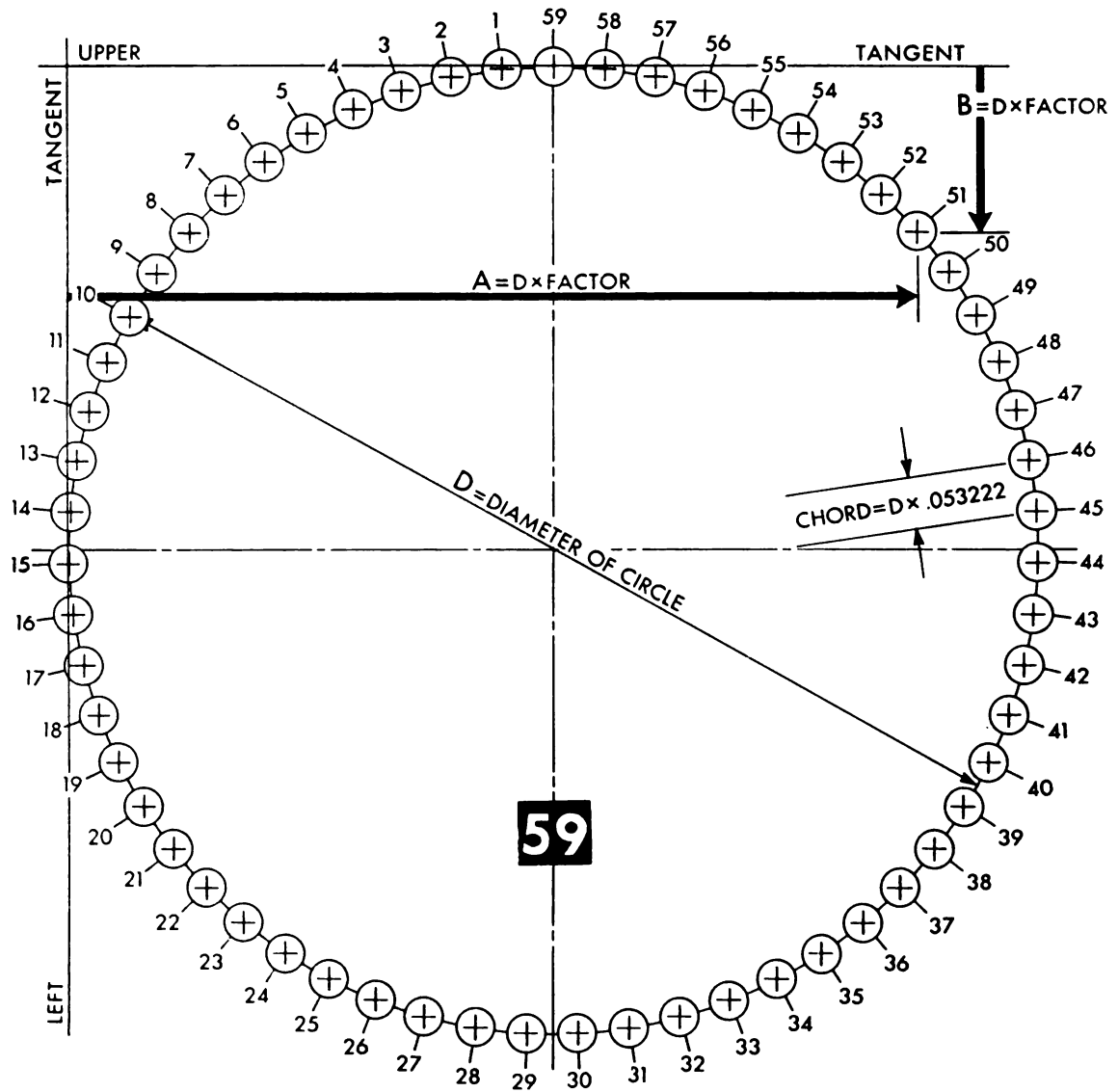


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.445941	1	.002931	1	6	12 24-48/58
2	.392515	2	.011689	2	12	24 49-38/58
3	.340349	3	.026173	3	18	37 14-28/58
4	.290056	4	.046212	4	24	49 39-18/58
5	.242223	5	.071571	5	31	2 4-8/58
6	.197413	6	.101954	6	37	14 28-56/58
7	.156150	7	.137002	7	43	26 53-46/58
8	.118919	8	.176305	8	49	39 18-36/58
9	.086155	9	.219407	9	55	51 43-26/58
10	.058244	10	.265796	10	62	4 8-16/58
11	.035511	11	.314931	11	68	16 33-6/58
12	.018225	12	.366236	12	74	28 57-54/58

# COORDINATE FACTORS AND ANGLES—58 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
13		.006587	13	.419109	13	80	41 22-44/58
14		.000733	14	.472931	14	86	53 47-34/58
15		.000733	15	.527070	15	93	6 12-24/58
16		.006587	16	.580891	16	99	18 37-14/58
17		.018225	17	.633764	17	105	31 2- 4/58
18		.035512	18	.685069	18	111	43 26-52/58
19		.058244	19	.734204	19	117	55 51-42/58
20		.086155	20	.780594	20	124	8 16-32/58
21		.118919	21	.823695	21	130	20 41-22/58
22		.156150	22	.862998	22	136	33 6-12/58
23		.197413	23	.898047	23	142	45 31- 2/58
24		.242223	24	.928429	24	148	57 55-50/58
25		.290056	25	.953788	25	155	10 20-40/58
26		.340349	26	.973827	26	161	22 45-30/58
27		.392515	27	.988311	27	167	35 10-20/58
28		.445941	28	.997069	28	173	47 35-10/58
29		.500000	29	1.000000	29	180	00 00000000
30		.554060	30	.997069	30	186	12 24-48/58
31		.607485	31	.988311	31	192	24 49-38/58
32		.659651	32	.973827	32	198	37 14-28/58
33		.709945	33	.953788	33	204	49 39-18/58
34		.757777	34	.928429	34	211	2 4- 8/58
35		.802587	35	.898047	35	217	14 28-56/58
36		.843850	36	.862998	36	223	26 53-46/58
37		.881081	37	.823695	37	229	39 18-36/58
38		.913845	38	.780594	38	235	51 43-26/58
39		.941756	39	.734204	39	242	4 8-16/58
40		.964488	40	.685069	40	248	16 33- 6/58
41		.981775	41	.633764	41	254	28 57-54/58
42		.993413	42	.580891	42	260	41 22-44/58
43		.999267	43	.527070	43	266	53 47-34/58
44		.999267	44	.472931	44	273	6 12-24/58
45		.993413	45	.419109	45	279	18 37-14/58
46		.981775	46	.366236	46	285	31 2- 4/58
47		.964488	47	.314931	47	291	43 26-52/58
48		.941756	48	.265796	48	297	55 51-42/58
49		.913845	49	.219407	49	304	8 16-32/58
50		.881081	50	.176305	50	310	20 41-22/58
51		.843850	51	.137002	51	316	33 6-12/58
52		.802587	52	.101954	52	322	45 31- 2/58
53		.757777	53	.071571	53	328	57 55-50/58
54		.709945	54	.046212	54	335	10 20-40/58
55		.659651	55	.026173	55	341	22 45-30/58
56		.607485	56	.011689	56	347	35 10-20/58
57		.554060	57	.002931	57	353	47 35-10/58
58		.500000	58	.000000	58	360	0 0

# 59 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

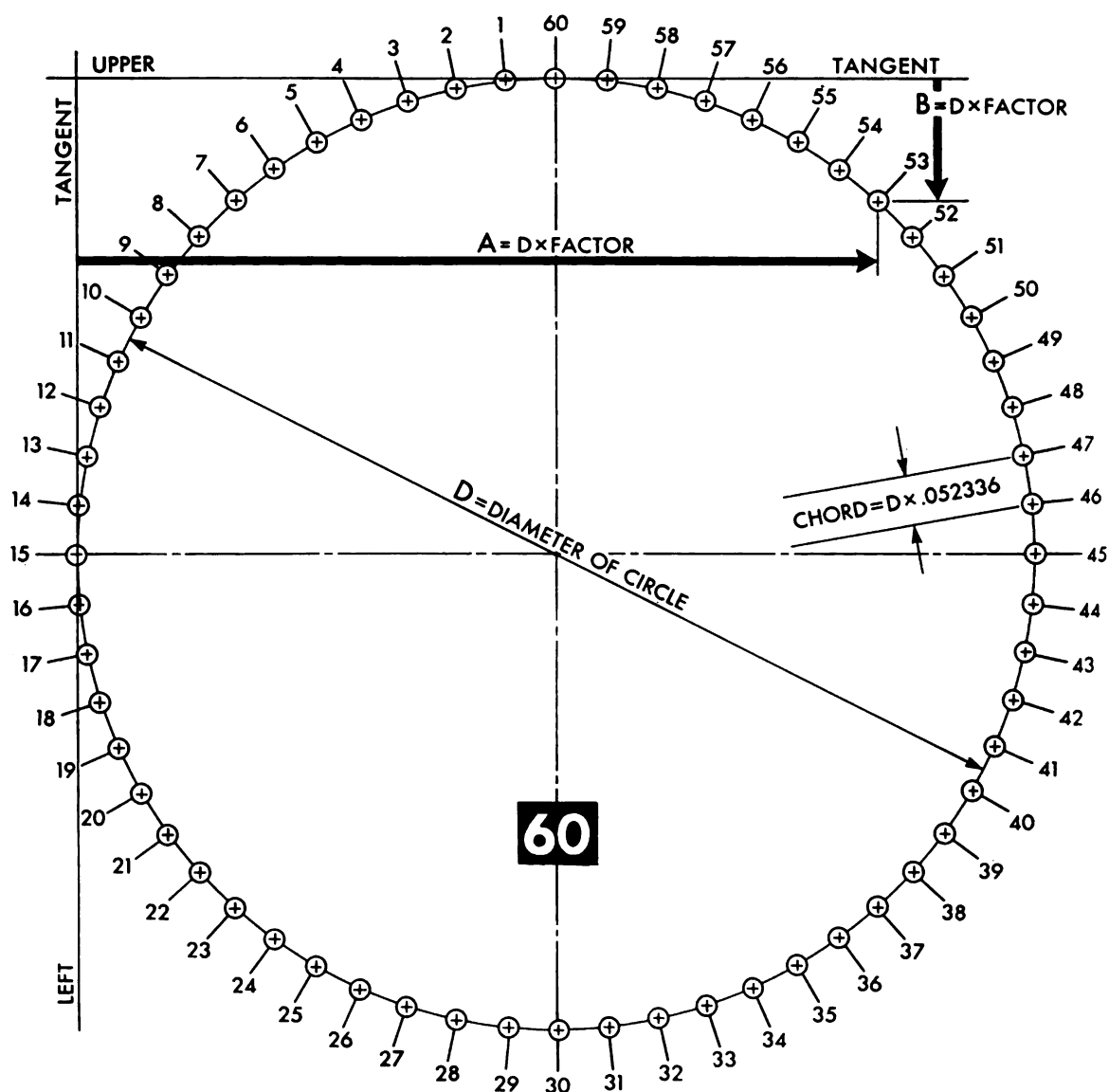


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.446853	1	.002833	1	6	6- 6 / 59
2		.394309	2	.011298	2	12	12-12 / 59
3		.342962	3	.025301	3	18	18-18 / 59
4		.293394	4	.044682	4	24	24-24 / 59
5		.246167	5	.069223	5	30	30-30 / 59
6		.201816	6	.098644	6	36	36-36 / 59
7		.160844	7	.132613	7	42	42-42 / 59
8		.123715	8	.170744	8	48	48-48 / 59
9		.090849	9	.212606	9	54	54-54 / 59
10		.062619	10	.257725	10	61	1- 1 / 59
11		.039344	11	.305588	11	67	7- 7 / 59
12		.021289	12	.355654	12	73	13-13 / 59

# COORDINATE FACTORS AND ANGLES—59 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
13		.008658	13	.407356	13	79	19-19/59
14		.001594	14	.460107	14	85	25-25/59
15		.000177	15	.513310	15	91	31-31/59
16		.004424	16	.566363	16	97	37-37/59
17		.014285	17	.618663	17	103	43-43/59
18		.029650	18	.669619	18	109	49-49/59
19		.050344	19	.718654	19	115	55-55/59
20		.076133	20	.765210	20	122	2- 2/59
21		.106724	21	.808762	21	128	8- 8/59
22		.141772	22	.848816	22	134	14-14/59
23		.180878	23	.884917	23	140	20-20/59
24		.223600	24	.916657	24	146	26-26/59
25		.269454	25	.943676	25	152	32-32/59
26		.317920	26	.965668	26	158	38-38/59
27		.368449	27	.982384	27	164	44-44/59
28		.420469	28	.993634	28	170	50-50/59
29		.473389	29	.999291	29	176	56-56/59
30		.526611	30	.999291	30	183	3- 3/59
31		.579532	31	.993634	31	189	9- 9/59
32		.631551	32	.982384	32	195	15-15/59
33		.682080	33	.965668	33	201	21-21/59
34		.730546	34	.943676	34	207	27-27/59
35		.776400	35	.916657	35	213	33-33/59
36		.819122	36	.884917	36	219	39-39/59
37		.858228	37	.848816	37	225	45-45/59
38		.893276	38	.808762	38	231	51-51/59
39		.923867	39	.765210	39	237	57-57/59
40		.949656	40	.718654	40	244	4- 4/59
41		.970350	41	.669619	41	250	10-10/59
42		.985715	42	.618663	42	256	16-16/59
43		.995576	43	.566363	43	262	22-22/59
44		.999823	44	.513310	44	268	28-28/59
45		.998406	45	.460107	45	274	34-34/59
46		.991342	46	.407356	46	280	40-40/59
47		.978711	47	.355654	47	286	46-46/59
48		.960656	48	.305588	48	292	52-52/59
49		.937382	49	.257725	49	298	58-58/59
50		.909151	50	.212606	50	305	5- 5/59
51		.876285	51	.170744	51	311	11-11/59
52		.839156	52	.132613	52	317	17-17/59
53		.798184	53	.098644	53	323	23-23/59
54		.753833	54	.069223	54	329	29-29/59
55		.706606	55	.044682	55	335	35-35/59
56		.657038	56	.025301	56	341	41-41/59
57		.605691	57	.011298	57	347	47-47/59
58		.553147	58	.002833	58	353	53-53/59
59		.500000	59	.000000	59	360	0

# 60 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

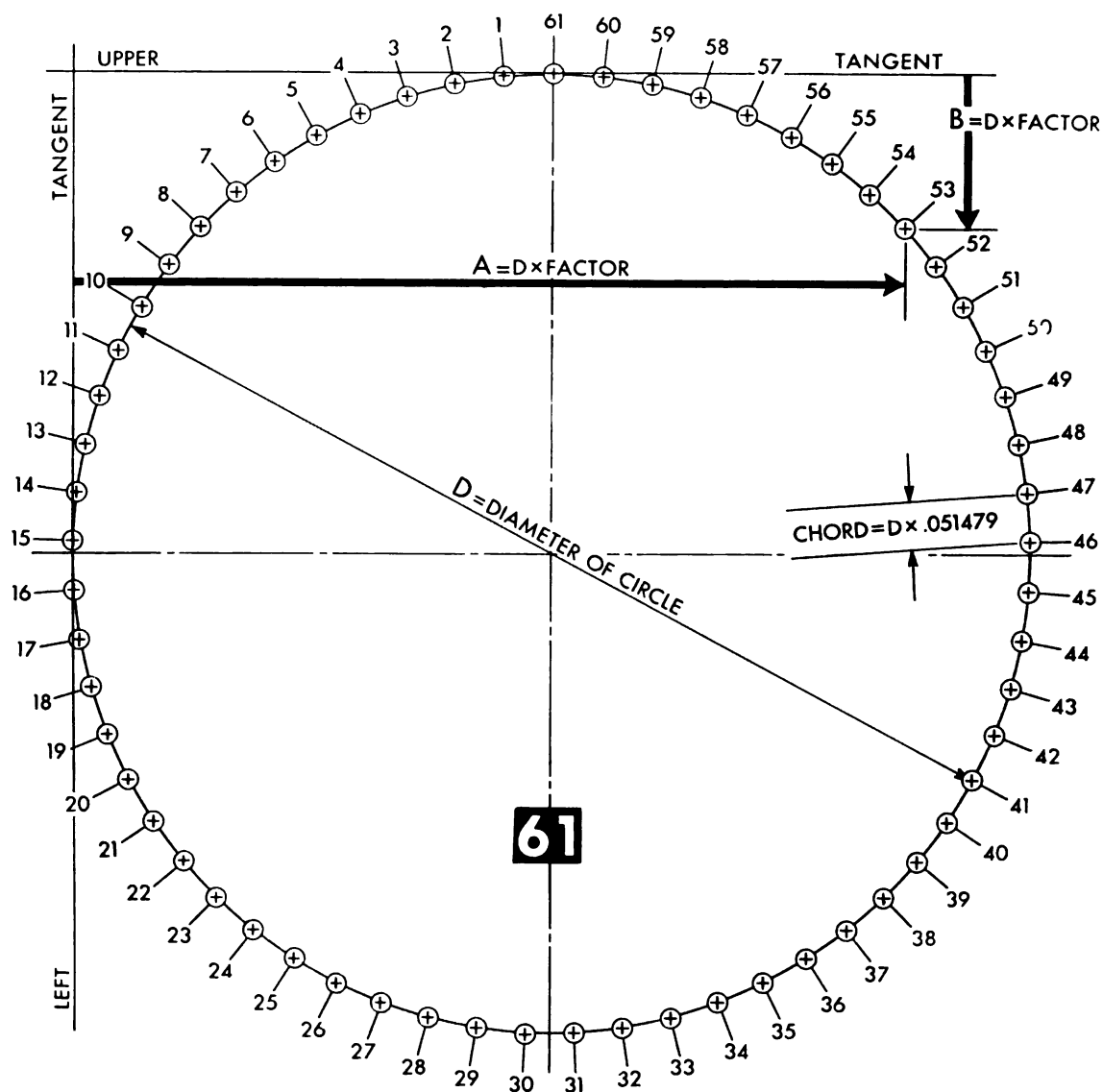


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.447736	1	.002739	1	6	0	0
2		.396044	2	.010926	2	12	0	0
3		.345492	3	.024472	3	18	0	0
4		.296632	4	.043227	4	24	0	0
5		.250000	5	.066988	5	30	0	0
6		.206107	6	.095492	6	36	0	0
7		.165435	7	.128428	7	42	0	0
8		.128428	8	.165435	8	48	0	0
9		.095492	9	.206107	9	54	0	0
10		.066987	10	.250000	10	60	0	0
11		.043227	11	.296632	11	66	0	0
12		.024472	12	.345492	12	72	0	0

# COORDINATE FACTORS AND ANGLES—60 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
13	.010926	13	.396044	13	78	0	0
14	.002739	14	.447736	14	84	0	0
15	.000000	15	.500000	15	90	0	0
16	.002739	16	.552264	16	96	0	0
17	.010926	17	.603956	17	102	0	0
18	.024472	18	.654509	18	108	0	0
19	.043227	19	.703368	19	114	0	0
20	.066987	20	.750000	20	120	0	0
21	.095492	21	.793893	21	126	0	0
22	.128428	22	.834565	22	132	0	0
23	.165435	23	.871572	23	138	0	0
24	.206107	24	.904509	24	144	0	0
25	.250000	25	.933013	25	150	0	0
26	.296632	26	.956773	26	156	0	0
27	.345492	27	.975528	27	162	0	0
28	.396044	28	.989074	28	168	0	0
29	.447736	29	.997261	29	174	0	0
30	.500000	30	1.000000	30	180	0	0
31	.552264	31	.997261	31	186	0	0
32	.603956	32	.989074	32	192	0	0
33	.654509	33	.975528	33	198	0	0
34	.703368	34	.956773	34	204	0	0
35	.750000	35	.933013	35	210	0	0
36	.793893	36	.904509	36	216	0	0
37	.834565	37	.871572	37	222	0	0
38	.871572	38	.834565	38	228	0	0
39	.904509	39	.793893	39	234	0	0
40	.933013	40	.750000	40	240	0	0
41	.956773	41	.703368	41	246	0	0
42	.975528	42	.654509	42	252	0	0
43	.989074	43	.603956	43	258	0	0
44	.997261	44	.552264	44	264	0	0
45	1.000000	45	.500000	45	270	0	0
46	.997261	46	.447736	46	276	0	0
47	.989074	47	.396044	47	282	0	0
48	.975528	48	.345492	48	288	0	0
49	.956773	49	.296632	49	294	0	0
50	.933013	50	.250000	50	300	0	0
51	.904509	51	.206107	51	306	0	0
52	.871572	52	.165435	52	312	0	0
53	.834565	53	.128428	53	318	0	0
54	.793893	54	.095492	54	324	0	0
55	.750000	55	.066988	55	330	0	0
56	.703368	56	.043227	56	336	0	0
57	.654509	57	.024472	57	342	0	0
58	.603956	58	.010926	58	348	0	0
59	.552264	59	.002739	59	354	0	0
60	.500000	60	.000000	60	360	0	0

# 61 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

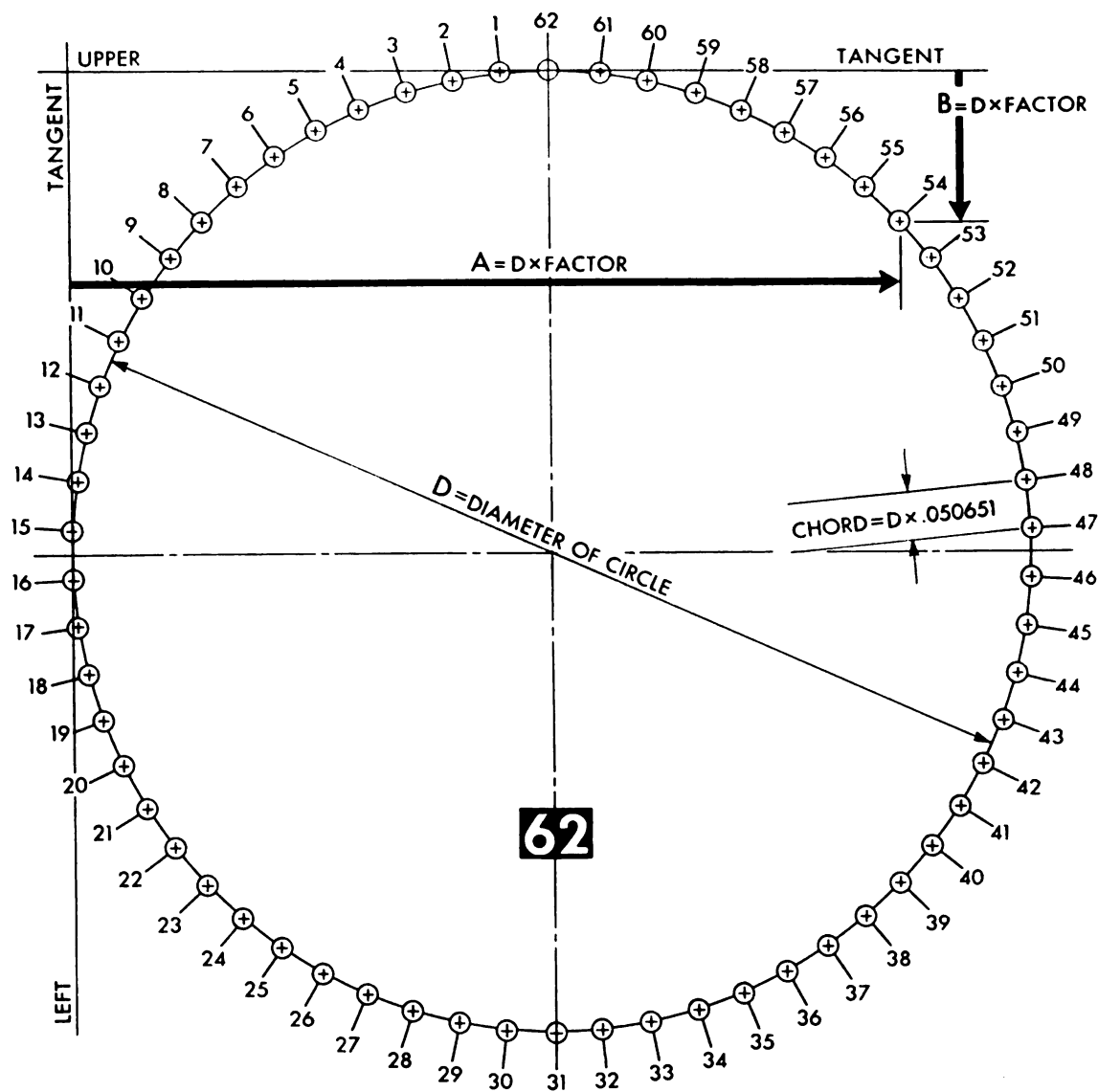


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.448590	1	.002650	1	5	54 5-55/61
2		.397724	2	.010572	2	11	48 11-49/61
3		.347943	3	.023682	3	17	42 17-43/61
4		.299773	4	.041842	4	23	36 23-37/61
5		.253726	5	.064857	5	29	30 29-31/61
6		.210290	6	.092486	6	35	24 35-25/61
7		.169924	7	.124434	7	41	18 41-19/61
8		.133057	8	.160363	8	47	12 47-13/61
9		.100080	9	.199893	9	53	6 53- 7/61
10		.071343	10	.242604	10	59	00 59- 1/61
11		.047149	11	.288043	11	64	55 4-56/61
12		.027755	12	.335729	12	70	49 10-50/61

# COORDINATE FACTORS AND ANGLES—61 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
13	.013368	13	.385156	13	76	43	16-44/61
14	.004139	14	.435801	14	82	37	22-38/61
15	.000166	15	.487126	15	88	31	28-32/61
16	.001491	16	.538588	16	94	25	34-26/61
17	.008101	17	.589640	17	100	19	40-20/61
18	.019925	18	.639743	18	106	13	46-14/61
19	.036838	19	.688364	19	112	7	52- 8/61
20	.058661	20	.734988	20	118	1	58- 2/61
21	.085162	21	.779122	21	123	56	3-57/61
22	.116060	22	.820297	22	129	50	9-51/61
23	.151028	23	.858076	23	135	44	15-45/61
24	.189695	24	.892060	24	141	38	21-39/61
25	.231652	25	.921888	25	147	32	27-33/61
26	.276453	26	.947244	26	153	26	33-27/61
27	.323624	27	.967859	27	159	20	39-21/61
28	.372664	28	.983514	28	165	14	45-15/61
29	.423055	29	.994044	29	171	8	51- 9/61
30	.474261	30	.999337	30	177	2	57- 3/61
31	.525739	31	.999337	31	182	57	2-58/61
32	.576945	32	.994044	32	188	51	8-52/61
33	.627336	33	.983514	33	194	45	14-46/61
34	.676376	34	.967859	34	200	39	20-40/61
35	.723547	35	.947244	35	206	33	26-34/61
36	.768348	36	.921888	36	212	27	32-28/61
37	.810305	37	.892060	37	218	21	38-22/61
38	.848972	38	.858076	38	224	15	44-16/61
39	.883940	39	.820297	39	230	9	50-10/61
40	.914839	40	.779122	40	236	3	56- 4/61
41	.941339	41	.734988	41	241	58	1-59/61
42	.963162	42	.688364	42	247	52	7-53/61
43	.980075	43	.639743	43	253	46	13-47/61
44	.991899	44	.589640	44	259	40	19-41/61
45	.998509	45	.538588	45	265	34	25-35/61
46	.999834	46	.487126	46	271	28	31-29/61
47	.995861	47	.435801	47	277	22	37-23/61
48	.986632	48	.385156	48	283	16	43-17/61
49	.972245	49	.335729	49	289	10	49-11/61
50	.952851	50	.288043	50	295	4	55- 5/61
51	.928657	51	.242604	51	300	59	00-60/61
52	.899920	52	.199893	52	306	53	6-54/61
53	.866943	53	.160363	53	312	47	12-48/61
54	.830076	54	.124434	54	318	41	18-42/61
55	.789711	55	.092486	55	324	35	24-36/61
56	.746274	56	.064857	56	330	29	30-30/61
57	.700227	57	.041842	57	336	23	36-24/61
58	.652057	58	.023682	58	342	17	42-18/61
59	.602276	59	.010572	59	348	11	48-12/61
60	.551410	60	.002650	60	354	5	54- 6/61
61	.500000	61	.000000	61	360	0	0

# 62 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

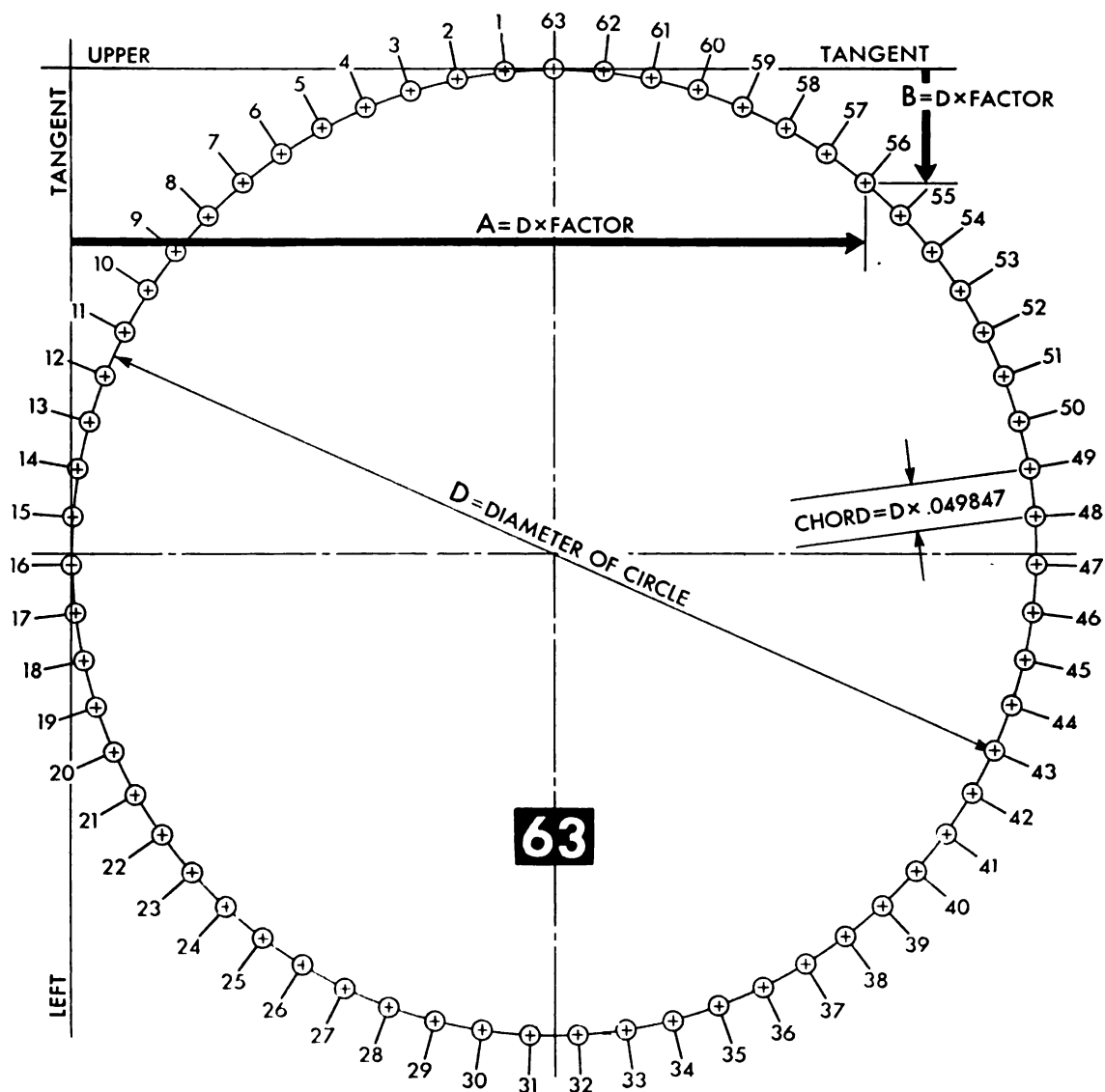


	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
1		.449416	1	.002565	1	5	48	23-14 62
2		.399351	2	.010235	2	11	36	46-28 62
3		.350318	3	.022930	3	17	25	9-42 62
4		.302822	4	.040521	4	23	13	32-56 62
5		.257349	5	.062827	5	29	1	56- 8 62
6		.214366	6	.089618	6	34	50	19-22 62
7		.174314	7	.120621	7	40	38	42-36 62
8		.137606	8	.155517	8	46	27	5-50 62
9		.104612	9	.193947	9	52	15	29- 2 62
10		.075678	10	.235518	10	58	3	52-16 62
11		.051098	11	.279803	11	63	52	15-30 62
12		.031124	12	.326347	12	69	40	38-44 62
13		.015961	13	.374674	13	75	29	1-58 62

# COORDINATE FACTORS AND ANGLES—62 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
14	.005766	14	.424286	14	81	17	25-10/62
15	.000642	15	.474675	15	87	5	48-24/62
16	.000642	16	.525325	16	92	54	11-38/62
17	.005766	17	.575714	17	98	42	34-52/62
18	.015961	18	.625326	18	104	30	58- 4/62
19	.031124	19	.673653	19	110	19	21-18/62
20	.051098	20	.720197	20	116	7	44-32/62
21	.075678	21	.764482	21	121	56	7-46/62
22	.104612	22	.806053	22	127	44	30-60/62
23	.137606	23	.844484	23	133	32	54-12/62
24	.174314	24	.879379	24	139	21	17-26/62
25	.214366	25	.910382	25	145	9	40-40/62
26	.257349	26	.937173	26	150	58	3-54/62
27	.302822	27	.959479	27	156	46	27- 6/62
28	.350318	28	.977070	28	162	34	50-20/62
29	.399351	29	.989765	29	168	23	13-34/62
30	.449416	30	.997435	30	174	11	36-48/62
31	.500000	31	1.000000	31	180	00	00000000
32	.550584	32	.997435	32	185	48	23-14/62
33	.600649	33	.989765	33	191	36	46-28/62
34	.649682	34	.977070	34	197	25	9-42/62
35	.697178	35	.959479	35	203	13	32-56/62
36	.742651	36	.937173	36	209	1	56- 8/62
37	.785634	37	.910382	37	214	50	19-22/62
38	.825686	38	.879379	38	220	38	42-36/62
39	.862394	39	.844484	39	226	27	5-50/62
40	.895388	40	.806053	40	232	15	29- 2/62
41	.924322	41	.764482	41	238	3	52-16/62
42	.948902	42	.720197	42	243	52	15-30/62
43	.968876	43	.673653	43	249	40	38-44/62
44	.984039	44	.625326	44	255	29	1-58/62
45	.994234	45	.575714	45	261	17	25-10/62
46	.999358	46	.525325	46	267	5	48-24/62
47	.999358	47	.474675	47	272	54	11-38/62
48	.994234	48	.424286	48	278	42	34-52/62
49	.984039	49	.374674	49	284	30	58- 4/62
50	.968876	50	.326347	50	290	19	21-18/62
51	.948902	51	.279803	51	296	7	44-32/62
52	.924322	52	.235518	52	301	56	7-46/62
53	.895388	53	.193947	53	307	44	30-60/62
54	.862394	54	.155517	54	313	32	54-12/62
55	.825686	55	.120621	55	319	21	17-26/62
56	.785634	56	.089618	56	325	9	40-40/62
57	.742651	57	.062827	57	330	58	3-54/62
58	.697178	58	.040521	58	336	46	27- 6/62
59	.649682	59	.022930	59	342	34	50-20/62
60	.600649	60	.010235	60	348	23	13-34/62
61	.550584	61	.002565	61	354	11	36-48/62
62	.500000	62	.000000	62	360	0	0

# 63 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

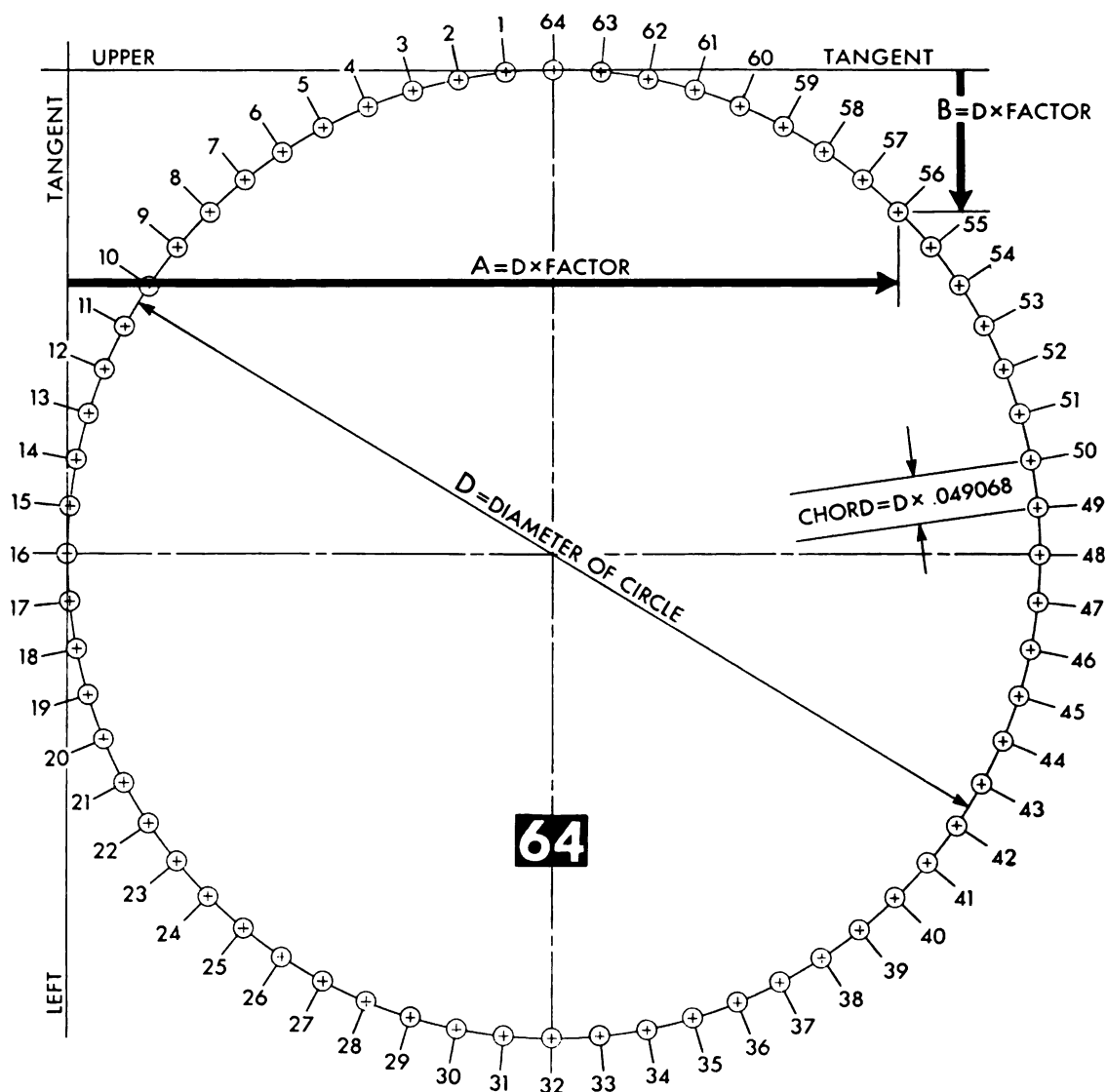


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.450216	1	.002485	1	5	42 51-27 / 63
2		.400927	2	.009914	2	11	25 42-54 / 63
3		.352622	3	.022214	3	17	8 34-18 / 63
4		.305783	4	.039262	4	22	51 25-45 / 63
5		.260873	5	.060889	5	28	34 17- 9 / 63
6		.218340	6	.086881	6	34	17 8-36 / 63
7		.178606	7	.116978	7	40	00 00000000
8		.142067	8	.150882	8	45	42 51-27 / 63
9		.109084	9	.188255	9	51	25 42-54 / 63
10		.079987	10	.228727	10	57	8 34-18 / 63
11		.055064	11	.271895	11	62	51 25-45 / 63
12		.034563	12	.317330	12	68	34 17- 9 / 63
13		.018688	13	.364580	13	74	17 8-36 / 63

# COORDINATE FACTORS AND ANGLES—63 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.007596	14	.413176	14	80	00 00000000
15	.001398	15	.462635	15	85	42 51-27/63
16	.000155	16	.512465	16	91	25 42-54/63
17	.003880	17	.562172	17	97	8 34-18/63
18	.012536	18	.611260	18	102	51 25-45/63
19	.026036	19	.659243	19	108	34 17- 9/63
20	.044247	20	.705644	20	114	17 8-36/63
21	.066987	21	.750000	21	120	00 00000000
22	.094031	22	.791872	22	125	42 51-27/63
23	.125109	23	.830843	23	131	25 42-54/63
24	.159914	24	.866526	24	137	8 34-18/63
25	.198098	25	.898566	25	142	51 25-45/63
26	.239282	26	.926645	26	148	34 17- 9/63
27	.283058	27	.950484	27	154	17 8-36/63
28	.328990	28	.969846	28	160	00 00000000
29	.376621	29	.984539	29	165	42 51-27/63
30	.425479	30	.994415	30	171	25 42-54/63
31	.475077	31	.999379	31	177	8 34-18/63
32	.524923	32	.999379	32	182	51 25-45/63
33	.574521	33	.994415	33	188	34 17- 9/63
34	.623379	34	.984539	34	194	17 8-36/63
35	.671010	35	.969846	35	200	00 00000000
36	.716942	36	.950484	36	205	42 51-27/63
37	.760718	37	.926645	37	211	25 42-54/63
38	.801902	38	.898566	38	217	8 34-18/63
39	.840086	39	.866526	39	222	51 25-45/63
40	.874891	40	.830843	40	228	34 17- 9/63
41	.905969	41	.791872	41	234	17 8-36/63
42	.933013	42	.750000	42	240	00 00000000
43	.955753	43	.705644	43	245	42 51-27/63
44	.973964	44	.659243	44	251	25 42-54/63
45	.987464	45	.611260	45	257	8 34-18/63
46	.996120	46	.562172	46	262	51 25-45/63
47	.999845	47	.512465	47	268	34 17- 9/63
48	.998602	48	.462635	48	274	17 8-36/63
49	.992404	49	.413176	49	280	00 00000000
50	.981312	50	.364580	50	285	42 51-27/63
51	.965437	51	.317330	51	291	25 42-54/63
52	.944936	52	.271895	52	297	8 34-18/63
53	.920013	53	.228727	53	302	51 25-45/63
54	.890916	54	.188255	54	308	34 17- 9/63
55	.857933	55	.150882	55	314	17 8-36/63
56	.821394	56	.116978	56	320	00 00000000
57	.781660	57	.086881	57	325	42 51-27/63
58	.739127	58	.060889	58	331	25 42-54/63
59	.694217	59	.039262	59	337	8 34-18/63
60	.647378	60	.022214	60	342	51 25-45/63
61	.599073	61	.009914	61	348	34 17- 9/63
62	.549784	62	.002485	62	354	17 8-36/63
63	.500000	63	.000000	63	360	0 0

# 64 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

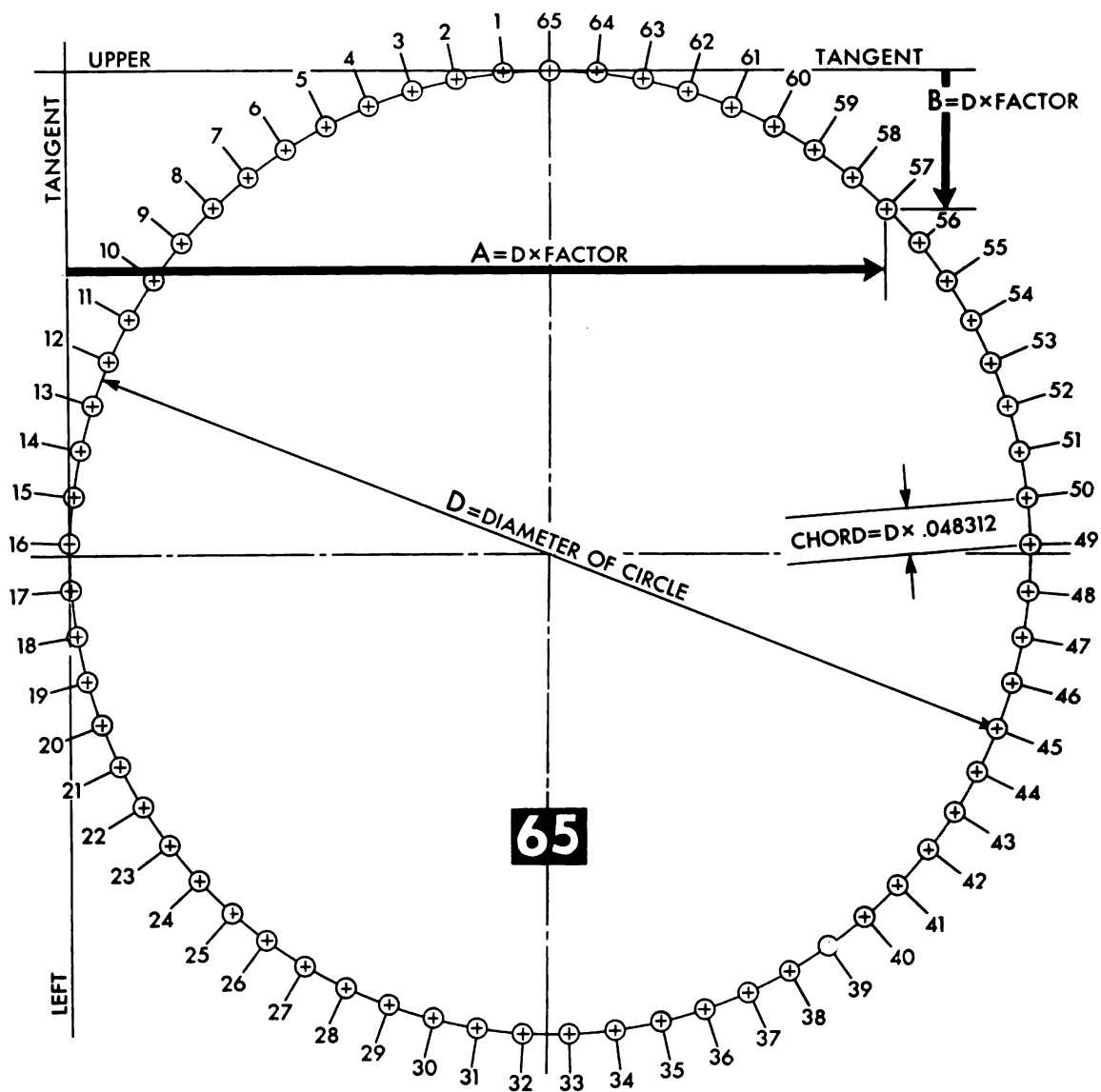


➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
1	.450992	1	.002408	1	5	37	30
2	.402455	2	.009607	2	11	15	00
3	.354858	3	.021530	3	16	52	30
4	.308658	4	.038060	4	22	30	00
5	.264302	5	.059039	5	28	7	30
6	.222215	6	.084265	6	33	45	00
7	.182803	7	.113495	7	39	22	30
8	.146447	8	.146447	8	45	00	00
9	.113495	9	.182803	9	50	37	30
10	.084265	10	.222215	10	56	15	00
11	.059039	11	.264302	11	61	52	30
12	.038060	12	.308658	12	67	30	00
13	.021530	13	.354858	13	73	7	30

# COORDINATE FACTORS AND ANGLES—64 HOLE DIVISION

	➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
14		.009607	14	.402455	14	78	45	00
15		.002408	15	.450992	15	84	22	30
16		.000000	16	.500000	16	90	00	00
17		.002408	17	.549009	17	95	37	30
18		.009607	18	.597545	18	101	15	00
19		.021530	19	.645142	19	106	52	30
20		.038060	20	.691342	20	112	30	00
21		.059039	21	.735698	21	118	7	30
22		.084265	22	.777785	22	123	45	00
23		.113495	23	.817197	23	129	22	30
24		.146447	24	.853553	24	135	00	00
25		.182803	25	.886505	25	140	37	30
26		.222215	26	.915735	26	146	15	00
27		.264302	27	.940961	27	151	52	30
28		.308658	28	.961940	28	157	30	00
29		.354858	29	.978470	29	163	7	30
30		.402455	30	.990393	30	168	45	00
31		.450992	31	.997592	31	174	22	30
32		.500000	32	1.000000	32	180	00	00
33		.549009	33	.997592	33	185	37	30
34		.597545	34	.990393	34	191	15	00
35		.645142	35	.978470	35	196	52	30
36		.691342	36	.961940	36	202	30	00
37		.735698	37	.940961	37	208	7	30
38		.777785	38	.915735	38	213	45	00
39		.817197	39	.886505	39	219	22	30
40		.853553	40	.853553	40	225	00	00
41		.886505	41	.817197	41	230	37	30
42		.915735	42	.777785	42	236	15	00
43		.940961	43	.735698	43	241	52	30
44		.961940	44	.691342	44	247	30	00
45		.978470	45	.645142	45	253	7	30
46		.990393	46	.597545	46	258	45	00
47		.997592	47	.549009	47	264	22	30
48		1.000000	48	.500000	48	270	00	00
49		.997592	49	.450992	49	275	37	30
50		.990393	50	.402455	50	281	15	00
51		.978470	51	.354858	51	286	52	30
52		.961940	52	.308658	52	292	30	00
53		.940961	53	.264302	53	298	7	30
54		.915735	54	.222215	54	303	45	00
55		.886505	55	.182803	55	309	22	30
56		.853553	56	.146447	56	315	00	00
57		.817197	57	.113495	57	320	37	30
58		.777785	58	.084265	58	326	15	00
59		.735698	59	.059039	59	331	52	30
60		.691342	60	.038060	60	337	30	00
61		.645142	61	.021530	61	343	7	30
62		.597545	62	.009607	62	348	45	0
63		.549009	63	.002408	63	354	22	30
64		.500000	64	.000000	64	360	0	0

# 65 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

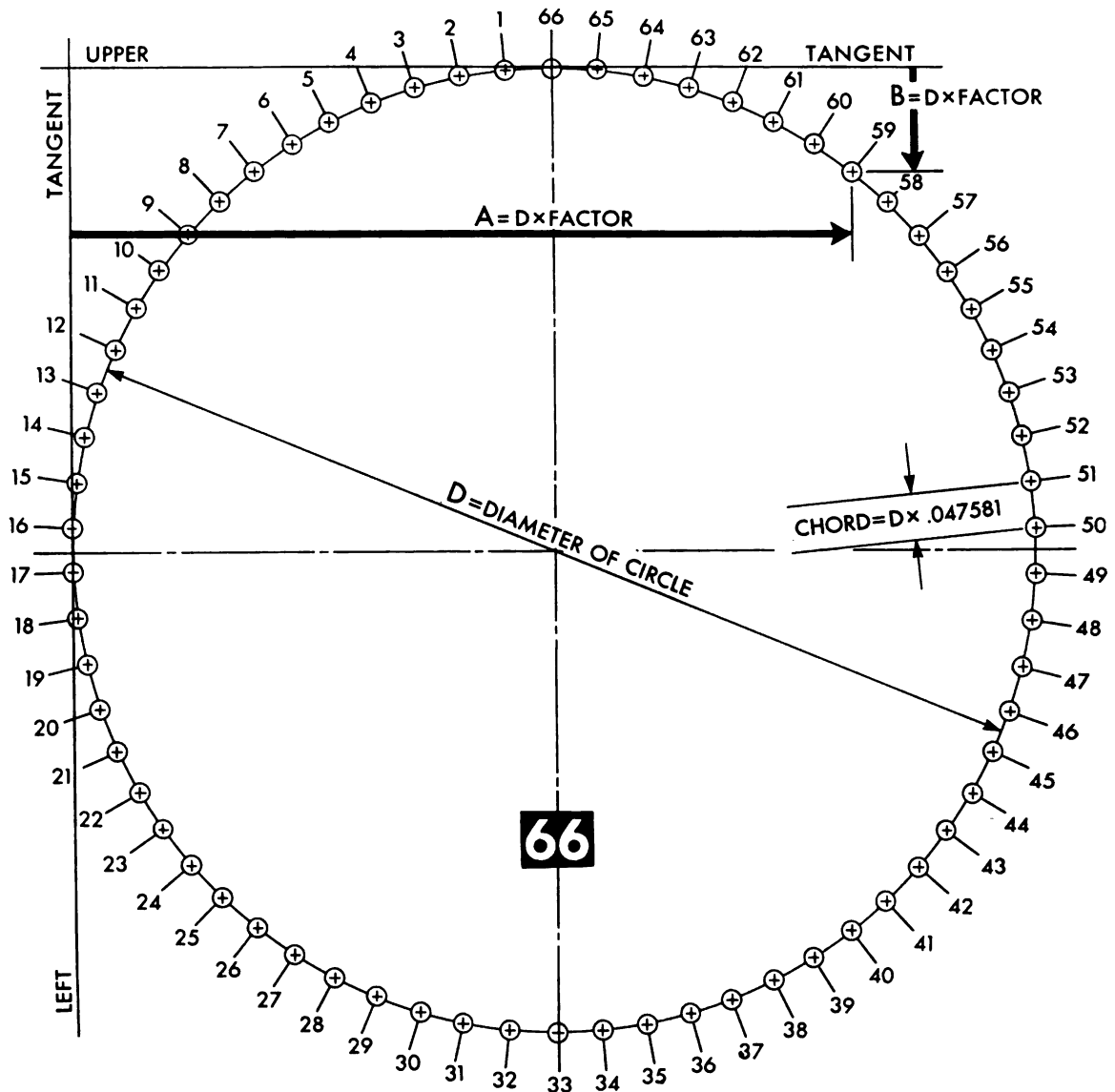


	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.451743	1	.002334	1	5	32	18-30/65
2	.403937	2	.009315	2	11	4	36-60/65
3	.357027	3	.020877	3	16	36	55-25/65
4	.311453	4	.036913	4	22	9	13-55/65
5	.267638	5	.057272	5	27	41	32-20/65
6	.225994	6	.081765	6	33	13	50-50/65
7	.186907	7	.110163	7	38	46	9-15/65
8	.150744	8	.142201	8	44	18	27-45/65
9	.117842	9	.177579	9	49	50	46-10/65
10	.088508	10	.215968	10	55	23	4-40/65
11	.063016	11	.257008	11	60	55	23- 5/65
12	.041604	12	.300318	12	66	27	41-35/65
13	.024472	13	.345492	13	72	00	00000000

# COORDINATE FACTORS AND ANGLES—65 HOLE DIVISION

	→ FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
14	.011780	14	.392108	14	77	32	18-30/65
15	.003646	15	.439732	15	83	4	36-60/65
16	.000146	16	.487918	16	88	36	55-25/65
17	.001313	17	.536217	17	94	9	13-55/65
18	.007137	18	.584179	18	99	41	32-20/65
19	.017562	19	.631354	19	105	13	50-50/65
20	.032492	20	.677302	20	110	46	9-15/65
21	.051787	21	.721596	21	116	18	27-45/65
22	.075266	22	.763820	22	121	50	46-10/65
23	.102711	23	.803581	23	127	23	4-40/65
24	.133866	24	.840508	24	132	55	23- 5/65
25	.168439	25	.874255	25	138	27	41-35/65
26	.206107	26	.904509	26	144	00	00000000
27	.246520	27	.930985	27	149	32	18-30/65
28	.289299	28	.953437	28	155	4	36-60/65
29	.334046	29	.971656	29	160	36	55-25/65
30	.380342	30	.985471	30	166	9	13-55/65
31	.427755	31	.994753	31	171	41	32-20/65
32	.475843	32	.999416	32	177	13	50-50/65
33	.524158	33	.999416	33	182	46	9-15/65
34	.572245	34	.994753	34	188	18	27-45/65
35	.619658	35	.985471	35	193	50	46-10/65
36	.665954	36	.971656	36	199	23	4-40/65
37	.710701	37	.953437	37	204	55	23- 5/65
38	.753480	38	.930985	38	210	27	41-35/65
39	.793893	39	.904509	39	216	00	00000000
40	.831561	40	.874255	40	221	32	18-30/65
41	.866134	41	.840508	41	227	4	36-60/65
42	.897289	42	.803581	42	232	36	55-25/65
43	.924734	43	.763820	43	238	9	13-55/65
44	.948214	44	.721596	44	243	41	32-20/65
45	.967508	45	.677302	45	249	13	50-50/65
46	.982438	46	.631354	46	254	46	9-15/65
47	.992863	47	.584179	47	260	18	27-45/65
48	.998687	48	.536217	48	265	50	46-10/65
49	.999854	49	.487918	49	271	23	4-40/65
50	.996354	50	.439732	50	276	55	23- 5/65
51	.988221	51	.392108	51	282	27	41-35/65
52	.975528	52	.345492	52	288	00	00000000
53	.958396	53	.300318	53	293	32	18-30/65
54	.936984	54	.257008	54	299	4	36-60/65
55	.911492	55	.215968	55	304	36	55-25/65
56	.882158	56	.177579	56	310	9	13-55/65
57	.849256	57	.142201	57	315	41	32-20/65
58	.813093	58	.110163	58	321	13	50-50/65
59	.774006	59	.081765	59	326	46	9-15/65
60	.732362	60	.057272	60	332	18	27-45/65
61	.688547	61	.036913	61	337	50	46-10/65
62	.642973	62	.020877	62	343	23	4-40/65
63	.596063	63	.009315	63	348	55	23- 5/65
64	.548257	64	.002334	64	354	27	41-35/65
65	.500000	65	.000000	65	360	0	0

# 66 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

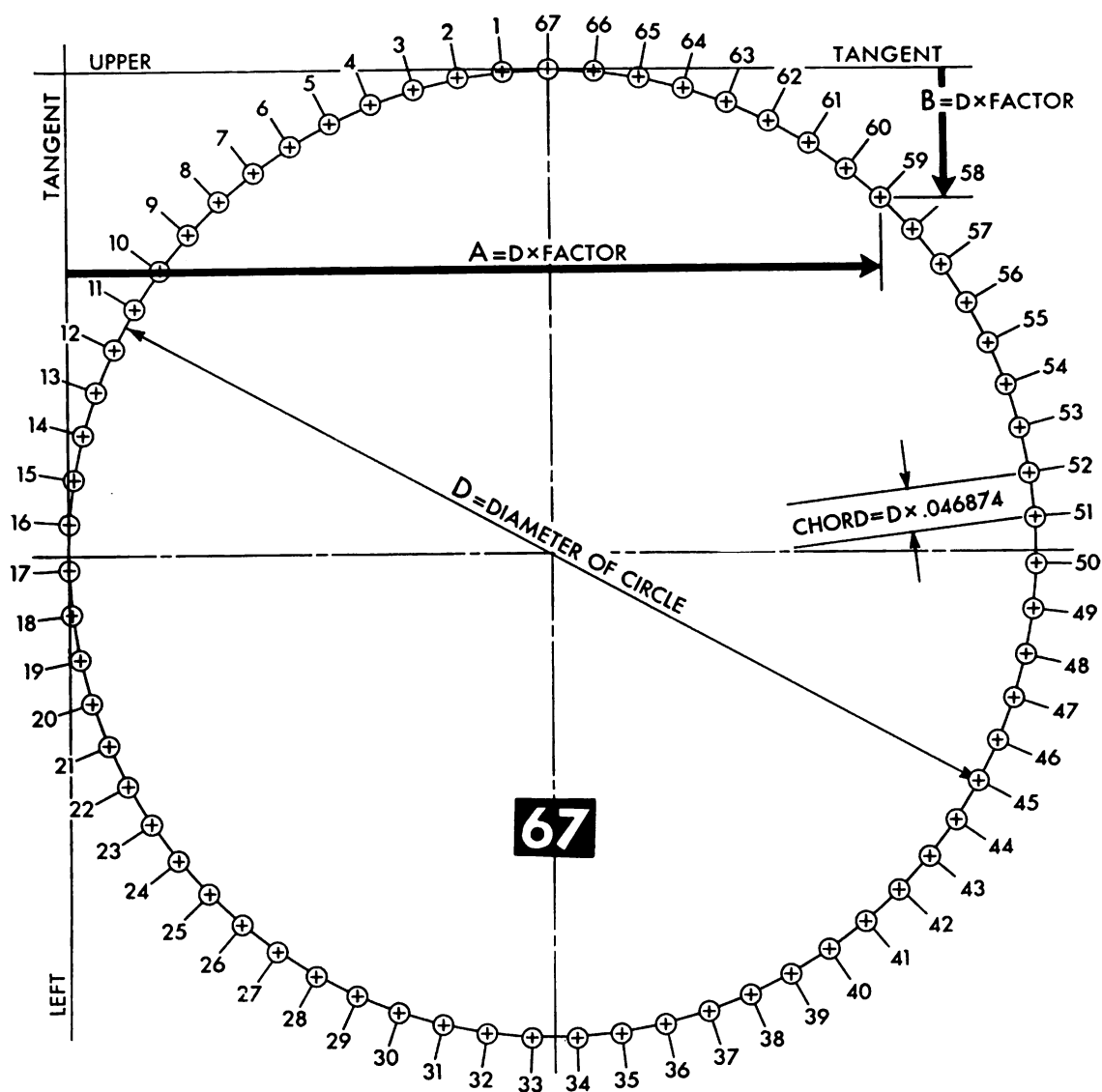


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.452472	1	.002264	1	5	27 16-24 '66
2		.405374	2	.009036	2	10	54 32-48 '66
3		.359134	3	.020254	3	16	21 49- 6 '66
4		.314169	4	.035816	4	21	49 5-30 '66
5		.270887	5	.055582	5	27	16 21-54 '66
6		.229680	6	.079373	6	32	43 38-12 '66
7		.190921	7	.106973	7	38	10 54-36 '66
8		.154961	8	.138133	8	43	38 10-60 '66
9		.122125	9	.172570	9	49	5 27-18 '66
10		.092712	10	.209972	10	54	32 43-42 '66
11		.066987	11	.250000	11	60	00 00000000
12		.045184	12	.292293	12	65	27 16-24 '66
13		.027500	13	.336466	13	70	54 32-48 '66

# COORDINATE FACTORS AND ANGLES—66 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.014094	14	.382121	14	76	21 49- 6/66
15	.005089	15	.428843	15	81	49 5-30/66
16	.000566	16	.476209	16	87	16 21-54/66
17	.000566	17	.523791	17	92	43 38-12/66
18	.005089	18	.571157	18	98	10 54-36/66
19	.014094	19	.617880	19	103	38 10-60/66
20	.027500	20	.663534	20	109	5 27-18/66
21	.045184	21	.707708	21	114	32 43-42/66
22	.066987	22	.750000	22	120	00 00000000
23	.092712	23	.790028	23	125	27 16-24/66
24	.122125	24	.827430	24	130	54 32-48/66
25	.154961	25	.861867	25	136	21 49- 6/66
26	.190921	26	.893027	26	141	49 5-30/66
27	.229680	27	.920627	27	147	16 21-54/66
28	.270887	28	.944418	28	152	43 38-12/66
29	.314169	29	.964184	29	158	10 54-36/66
30	.359134	30	.979747	30	163	38 10-60/66
31	.405374	31	.990964	31	169	5 27-18/66
32	.452472	32	.997736	32	174	32 43-42/66
33	.500000	33	1.000000	33	180	00 00000000
34	.547528	34	.997736	34	185	27 16-24/66
35	.594626	35	.990964	35	190	54 32-48/66
36	.640866	36	.979747	36	196	21 49- 6/66
37	.685831	37	.964184	37	201	49 5-30/66
38	.729113	38	.944418	38	207	16 21-54/66
39	.770320	39	.920627	39	212	43 38-12/66
40	.809080	40	.893027	40	218	10 54-36/66
41	.845040	41	.861867	41	223	38 10-60/66
42	.877875	42	.827430	42	229	5 27-18/66
43	.907288	43	.790028	43	234	32 43-42/66
44	.933013	44	.750000	44	240	00 00000000
45	.954816	45	.707708	45	245	27 16-24/66
46	.972500	46	.663534	46	250	54 32-48/66
47	.985906	47	.617880	47	256	21 49- 6/66
48	.994911	48	.571157	48	261	49 5-30/66
49	.999434	49	.523791	49	267	16 21-54/66
50	.999434	50	.476209	50	272	43 38-12/66
51	.994911	51	.428843	51	278	10 54-36/66
52	.985906	52	.382121	52	283	38 10-60/66
53	.972500	53	.336466	53	289	5 27-18/66
54	.954816	54	.292293	54	294	32 43-42/66
55	.933013	55	.250000	55	300	00 00000000
56	.907288	56	.209972	56	305	27 16-24/66
57	.877875	57	.172570	57	310	54 32-48/66
58	.845040	58	.138133	58	316	21 49- 6/66
59	.809080	59	.106973	59	321	49 5-30/66
60	.770320	60	.079373	60	327	16 21-54/66
61	.729113	61	.055582	61	332	43 38-12/66
62	.685831	62	.035816	62	338	10 54-36/66
63	.640866	63	.020254	63	343	38 10-60/66
64	.594626	64	.009036	64	349	5 27-18/66
65	.547528	65	.002264	65	354	32 43-42/66
66	.500000	66	.000000	66	360	0 0

# 67 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

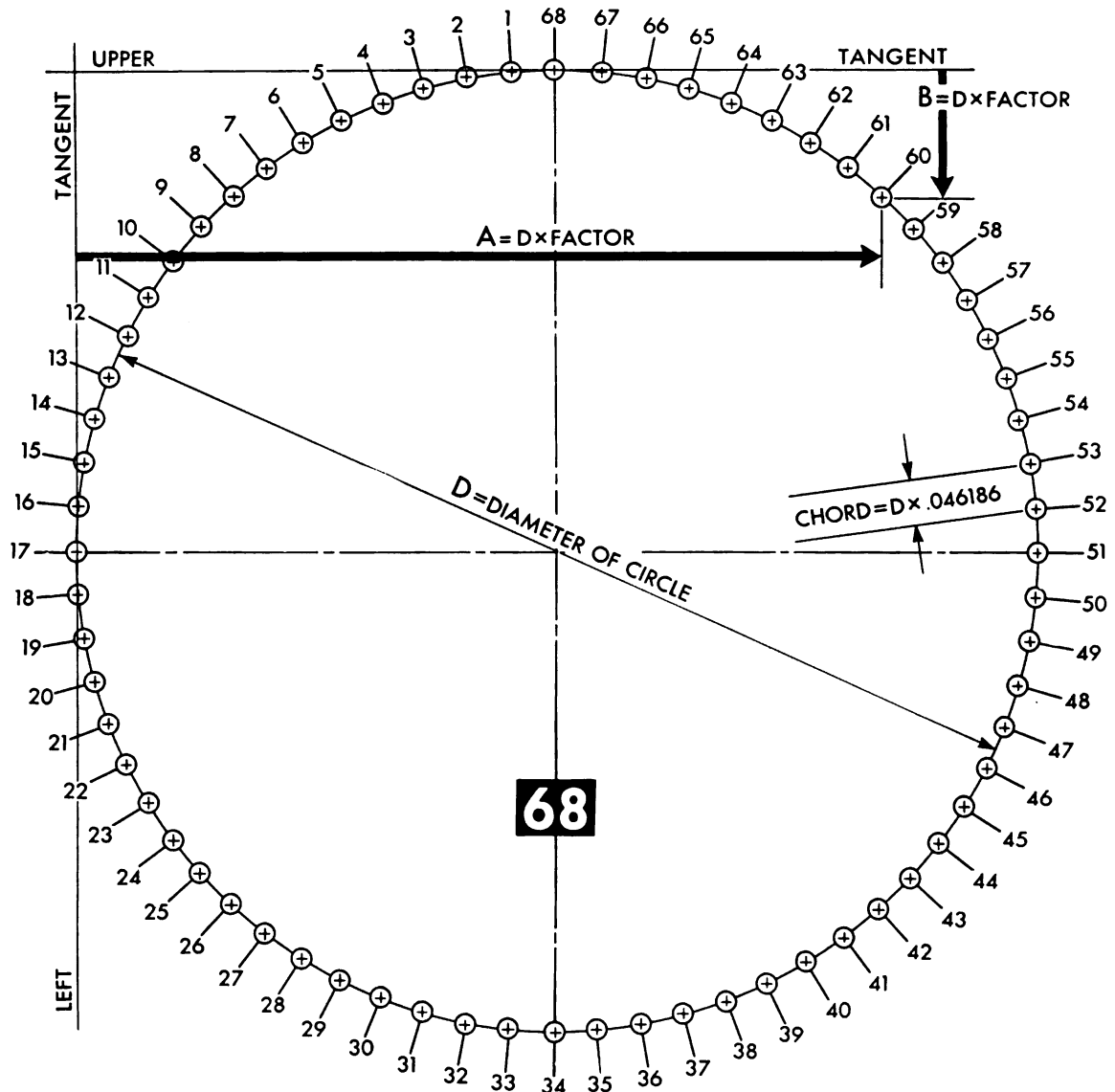


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.453180	1	.002197	1	5	22	23-19/67
2	.406770	2	.008769	2	10	44	46-38/67
3	.361180	3	.019657	3	16	7	9-57/67
4	.316810	4	.034767	4	21	29	33- 9/67
5	.274050	5	.053966	5	26	51	56-28/67
6	.233275	6	.077084	6	32	14	19-47/67
7	.194845	7	.103919	7	37	36	42-66/67
8	.159096	8	.134234	8	42	59	6-18/67
9	.126343	9	.167764	9	48	21	29-37/67
10	.096874	10	.204214	10	53	43	52-56/67
11	.070948	11	.243263	11	59	6	16- 8/67
12	.048792	12	.284568	12	64	28	39-27/67
13	.030601	13	.327767	13	69	51	2-46/67
14	.016535	14	.372479	14	75	13	25-65/67

# COORDINATE FACTORS AND ANGLES—67 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.006718	15	.418311	15	80	35 49-17/67
16	.001236	16	.464862	16	85	58 12-36/67
17	.000137	17	.511721	17	91	20 35-55/67
18	.003431	18	.558478	18	96	42 59- 7/67
19	.011089	19	.604720	19	102	5 22-26/67
20	.023044	20	.650042	20	107	27 45-45/67
21	.039190	21	.694046	21	112	50 8-64/67
22	.059385	22	.736344	22	118	12 32-16/67
23	.083453	23	.776566	23	123	34 55-35/67
24	.111181	24	.814356	24	128	57 18-54/67
25	.142327	25	.849385	25	134	19 42- 6/67
26	.176615	26	.881343	26	139	42 5-25/67
27	.213746	27	.909949	27	145	4 28-44/67
28	.253392	28	.934953	28	150	26 51-63/67
29	.295205	29	.956135	29	155	49 15-15/67
30	.338818	30	.973308	30	161	11 38-34/67
31	.383847	31	.986322	31	166	34 1-53/67
32	.429898	32	.995061	32	171	56 25- 5/67
33	.476564	33	.999450	33	177	18 48-24/67
34	.523436	34	.999450	34	182	41 11-43/67
35	.570102	35	.995061	35	188	3 34-62/67
36	.616153	36	.986322	36	193	25 58-14/67
37	.661182	37	.973308	37	198	48 21-33/67
38	.704795	38	.956135	38	204	10 44-52/67
39	.746609	39	.934953	39	209	33 8- 4/67
40	.786255	40	.909949	40	214	55 31-23/67
41	.823385	41	.881343	41	220	17 54-42/67
42	.857674	42	.849385	42	225	40 17-61/67
43	.888819	43	.814356	43	231	2 41-13/67
44	.916547	44	.776566	44	236	25 4-32/67
45	.940615	45	.736344	45	241	47 27-51/67
46	.960810	46	.694046	46	247	9 51- 3/67
47	.976956	47	.650042	47	252	32 14-22/67
48	.988911	48	.604720	48	257	54 37-41/67
49	.996569	49	.558478	49	263	17 00-60/67
50	.999863	50	.511721	50	268	39 24-12/67
51	.998764	51	.464862	51	274	1 47-31/67
52	.993282	52	.418311	52	279	24 10-50/67
53	.983465	53	.372479	53	284	46 34- 2/67
54	.969399	54	.327767	54	290	8 57-21/67
55	.951209	55	.284568	55	295	31 20-40/67
56	.929053	56	.243263	56	300	53 43-59/67
57	.903126	57	.204214	57	306	16 7-11/67
58	.873657	58	.167764	58	311	38 30-30/67
59	.840904	59	.134234	59	317	00 53-49/67
60	.805155	60	.103919	60	322	23 17- 1/67
61	.766725	61	.077084	61	327	45 40-20/67
62	.725950	62	.053966	62	333	8 3-39/67
63	.683190	63	.034767	63	338	30 26-58/67
64	.638820	64	.019657	64	343	52 50-10/67
65	.593230	65	.008769	65	349	15 13-29/67
66	.546820	66	.002197	66	354	37 36-48/67
67	.500000	67	.000000	67	360	0 0

# 68 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

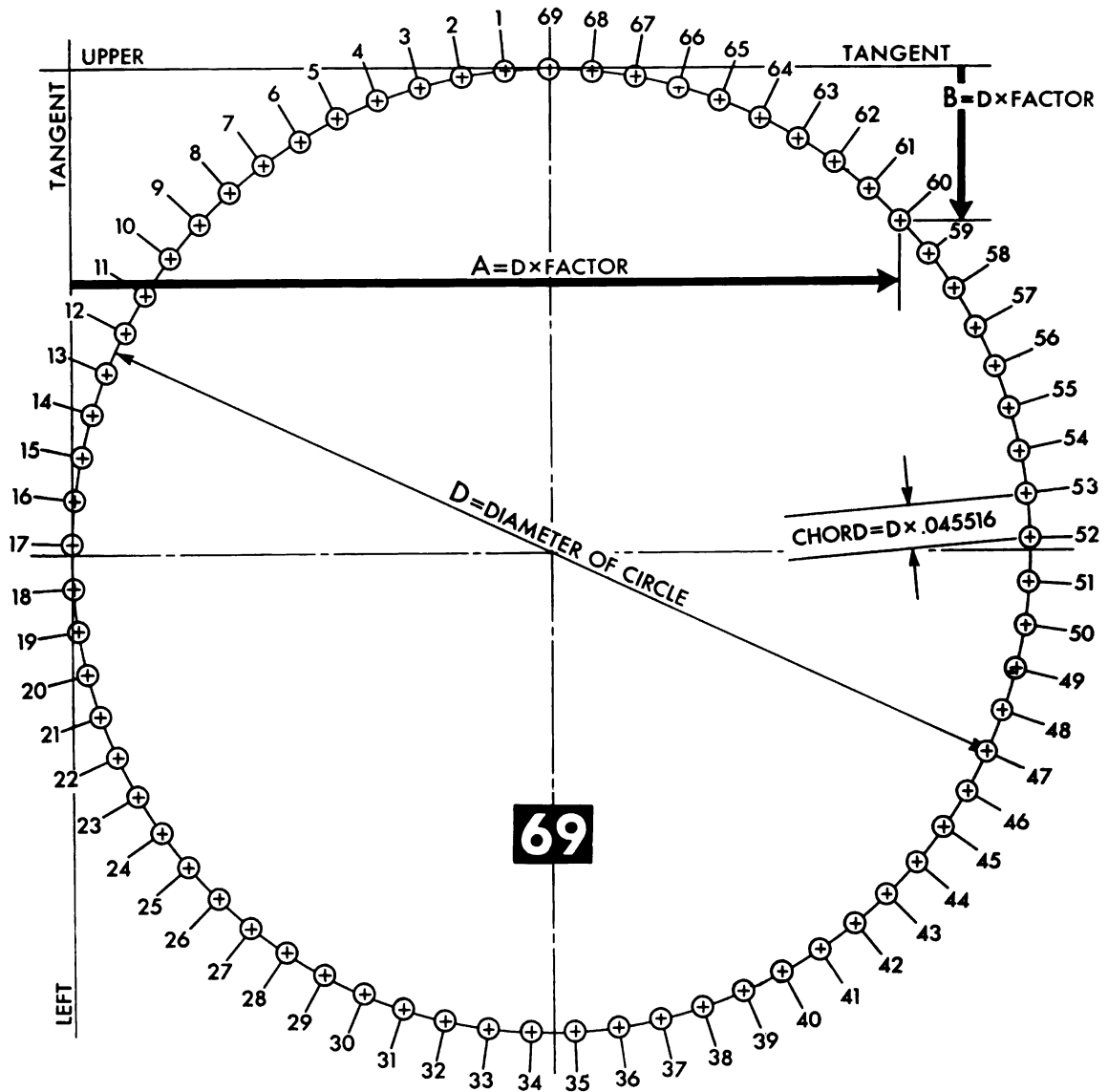


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.453866	1	.002133	1	5	17	38-56/68
2	.408125	2	.008514	2	10	35	17-44/68
3	.363169	3	.019087	3	15	52	56-32/68
4	.319379	4	.033764	4	21	10	35-20/68
5	.277131	5	.052418	5	26	28	14- 8/68
6	.236784	6	.074891	6	31	45	52-64/68
7	.198683	7	.100991	7	37	3	31-52/68
8	.163152	8	.130496	8	42	21	10-40/68
9	.130496	9	.163152	9	47	38	49-28/68
10	.100991	10	.198683	10	52	56	28-16/68
11	.074891	11	.236784	11	58	14	7- 4/68
12	.052418	12	.277131	12	63	31	45-60/68
13	.033764	13	.319379	13	68	49	24-48/68
14	.019087	14	.363169	14	74	7	3-36/68

# COORDINATE FACTORS AND ANGLES—68 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B" ↓	ANGLE OF HOLE		
			DEG.	MIN.	SEC.
15	.008514	15	.408125	15	79 24 42-24/68
16	.002133	16	.453866	16	84 42 21-12/68
17	.000000	17	.500000	17	90 00 00000000
18	.002133	18	.546134	18	95 17 38-56/68
19	.008514	19	.591875	19	100 35 17-44/68
20	.019087	20	.636832	20	105 52 56-32/68
21	.033764	21	.680621	21	111 10 35-20/68
22	.052418	22	.722869	22	116 28 14- 8/68
23	.074891	23	.763216	23	121 45 52-64/68
24	.100991	24	.801317	24	127 3 31-52/68
25	.130496	25	.836848	25	132 21 10-40/68
26	.163152	26	.869504	26	137 38 49-28/68
27	.198683	27	.899009	27	142 56 28-16/68
28	.236784	28	.925109	28	148 14 7- 4/68
29	.277131	29	.947582	29	153 31 45-60/68
30	.319379	30	.966236	30	158 49 24-48/68
31	.363169	31	.980913	31	164 7 3-36/68
32	.408125	32	.991487	32	169 24 42-24/68
33	.453866	33	.997867	33	174 42 21-12/68
34	.500000	34	1.000000	34	180 00 00000000
35	.546134	35	.997867	35	185 17 38-56/68
36	.591875	36	.991487	36	190 35 17-44/68
37	.636832	37	.980913	37	195 52 56-32/68
38	.680621	38	.966236	38	201 10 35-20/68
39	.722869	39	.947582	39	206 28 14- 8/68
40	.763216	40	.925109	40	211 45 52-64/68
41	.801317	41	.899009	41	217 3 31-52/68
42	.836848	42	.869504	42	222 21 10-40/68
43	.869504	43	.836848	43	227 38 49-28/68
44	.899009	44	.801317	44	232 56 28-16/68
45	.925109	45	.763216	45	238 14 7- 4/68
46	.947582	46	.722869	46	243 31 45-60/68
47	.966236	47	.680621	47	248 49 24-48/68
48	.980913	48	.636832	48	254 7 3-36/68
49	.991487	49	.591875	49	259 24 42-24/68
50	.997867	50	.546134	50	264 42 21-12/68
51	1.000000	51	.500000	51	270 00 00000000
52	.997867	52	.453866	52	275 17 38-56/68
53	.991487	53	.408125	53	280 35 17-44/68
54	.980913	54	.363169	54	285 52 56-32/68
55	.966236	55	.319379	55	291 10 35-20/68
56	.947582	56	.277131	56	296 28 14- 8/68
57	.925109	57	.236784	57	301 45 52-64/68
58	.899009	58	.198683	58	307 3 31-52/68
59	.869504	59	.163152	59	312 21 10-40/68
60	.836848	60	.130496	60	317 38 49-28/68
61	.801317	61	.100991	61	322 56 28-16/68
62	.763216	62	.074891	62	328 14 7- 4/68
63	.722869	63	.052418	63	333 31 45-60/68
64	.680621	64	.033764	64	338 49 24-48/68
65	.636832	65	.019087	65	344 7 3-36/68
66	.591875	66	.008514	66	349 24 42-24/68
67	.546134	67	.002133	67	354 42 21-12/68
68	.500000	68	.000000	68	360 0 0

# 69 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.454533	1	.002072	1	5	13	2-42/69
2	.409442	2	.008269	2	10	26	5-15/69
3	.365102	3	.018541	3	15	39	7-57/69
4	.321880	4	.032803	4	20	52	10-30/69
5	.280133	5	.050936	5	26	5	13- 3/69
6	.240208	6	.072790	6	31	18	15-45/69
7	.202436	7	.098185	7	36	31	18-18/69
8	.167130	8	.126908	8	41	44	20-60/69
9	.134582	9	.158723	9	46	57	23-33/69
10	.105062	10	.193367	10	52	10	26- 6/69
11	.078815	11	.230551	11	57	23	28-48/69
12	.056057	12	.269968	12	62	36	31-21/69
13	.036979	13	.311290	13	67	49	33-63/69
14	.021737	14	.354177	14	73	2	36-36/69

# COORDINATE FACTORS AND ANGLES—69 HOLE DIVISION

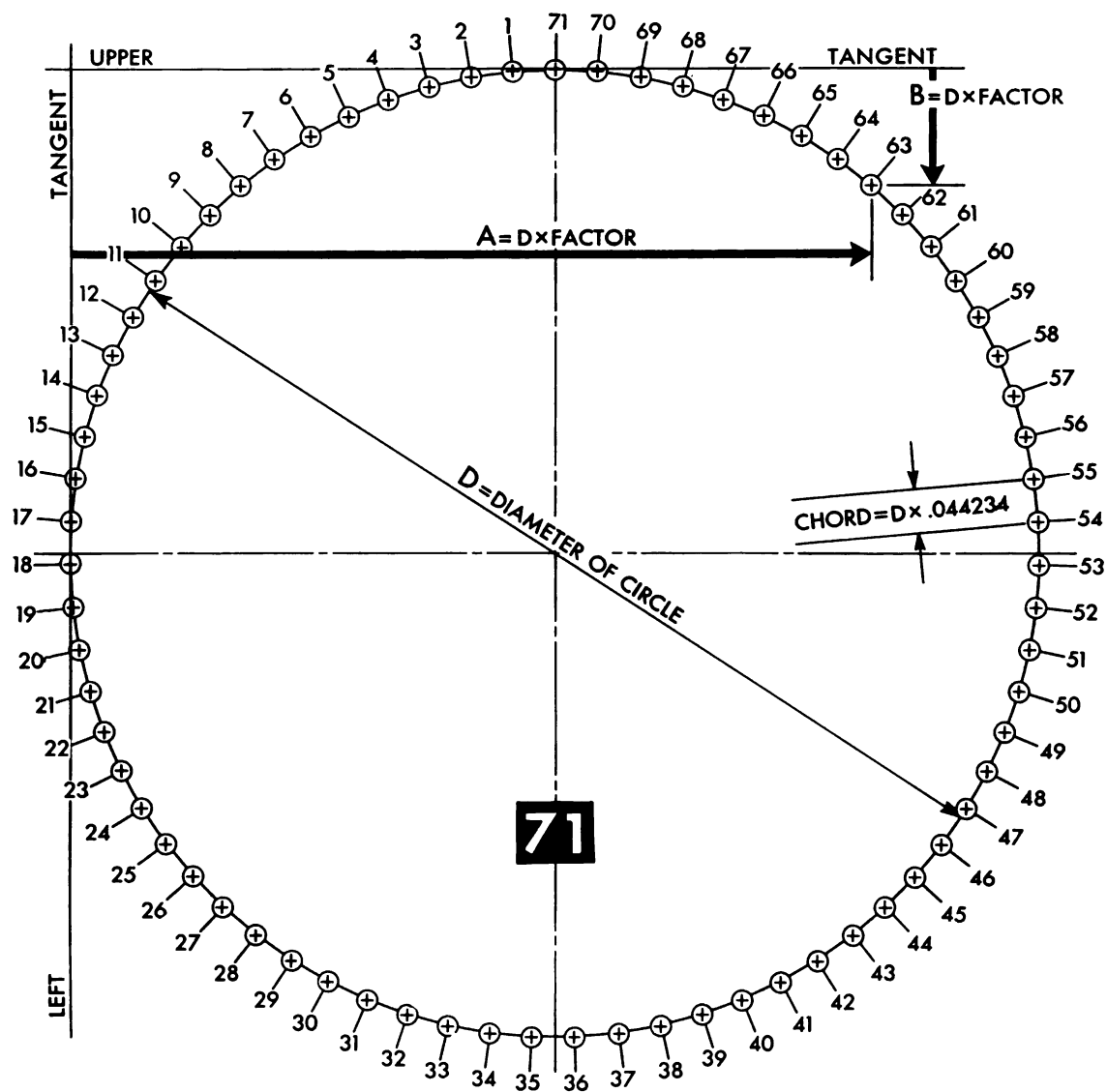
	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
15		.010458	15	.398272	15	78	39- 9/69
16		.003236	16	.443210	16	83	41-51/69
17		.000130	17	.488618	17	88	44-24/69
18		.001166	18	.534121	18	93	46-66/69
19		.006335	19	.579341	19	99	49-39/69
20		.015595	20	.623904	20	104	52-12/69
21		.028870	21	.667440	21	109	54-54/69
22		.046048	22	.709588	22	114	57-27/69
23		.066987	23	.750000	23	120	00000000
24		.091515	24	.788340	24	125	2-42/69
25		.119428	25	.824291	25	130	5-15/69
26		.150493	26	.857555	26	135	7-57/69
27		.184456	27	.887856	27	140	10-30/69
28		.221033	28	.914943	28	146	13- 3/69
29		.259922	29	.938591	29	151	15-45/69
30		.300800	30	.958606	30	156	18-18/69
31		.343328	31	.974820	31	161	20-60/69
32		.387155	32	.987100	32	166	23-33/69
33		.431917	33	.995343	33	172	26- 6/69
34		.477243	34	.999482	34	177	28-48/69
35		.522757	35	.999482	35	182	31-21/69
36		.568083	36	.995343	36	187	33-63/69
37		.612845	37	.987100	37	193	36-36/69
38		.656672	38	.974820	38	198	39- 9/69
39		.699201	39	.958606	39	203	41-51/69
40		.740079	40	.938591	40	208	44-24/69
41		.778967	41	.914943	41	213	46-66/69
42		.815544	42	.887856	42	219	49-39/69
43		.849507	43	.857555	43	224	52-12/69
44		.880572	44	.824291	44	229	54-54/69
45		.908485	45	.788340	45	234	57-27/69
46		.933013	46	.750000	46	240	00000000
47		.953952	47	.709588	47	245	2-42/69
48		.971131	48	.667440	48	250	5-15/69
49		.984405	49	.623904	49	255	7-57/69
50		.993665	50	.579341	50	260	10-30/69
51		.998834	51	.534121	51	266	13- 3/69
52		.999870	52	.488618	52	271	15-45/69
53		.996764	53	.443210	53	276	18-18/69
54		.989542	54	.398272	54	281	20-60/69
55		.978263	55	.354177	55	286	23-33/69
56		.963021	56	.311290	56	292	26- 6/69
57		.943943	57	.269968	57	297	28-48/69
58		.921185	58	.230551	58	302	31-21/69
59		.894938	59	.193367	59	307	33-63/69
60		.865418	60	.158723	60	313	36-36/69
61		.832870	61	.126908	61	318	39- 9/69
62		.797564	62	.098185	62	323	41-51/69
63		.759792	63	.072790	63	328	44-24/69
64		.719867	64	.050936	64	333	46-66/69
65		.678121	65	.032803	65	339	49-39/69
66		.634898	66	.018541	66	344	52-12/69
67		.590558	67	.008269	67	349	54-54/69
68		.545467	68	.002072	68	354	57-27/69
69		.500000	69	.000000	69	360	0

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# COORDINATE FACTORS AND ANGLES—70 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.012536	15	.388740	15	77	8 34-20/70
16	.004525	16	.432883	16	82	17 8-40/70
17	.000504	17	.477567	17	87	25 42-60/70
18	.000504	18	.522433	18	92	34 17-10/70
19	.004525	19	.567117	19	97	42 51-30/70
20	.012536	20	.611261	20	102	51 25-50/70
21	.024472	21	.654509	21	108	00 00000000
22	.040236	22	.696513	22	113	8 34-20/70
23	.059702	23	.736934	23	118	17 8-40/70
24	.082713	24	.775449	24	123	25 42-60/70
25	.109084	25	.811745	25	128	34 17-10/70
26	.138603	26	.845531	26	133	42 51-30/70
27	.171031	27	.876536	27	138	51 25-50/70
28	.206107	28	.904509	28	144	00 00000000
29	.243550	29	.929224	29	149	8 34-20/70
30	.283058	30	.950484	30	154	17 8-40/70
31	.324313	31	.968117	31	159	25 42-60/70
32	.366982	32	.981981	32	164	34 17-10/70
33	.410722	33	.991965	33	169	42 51-30/70
34	.455180	34	.997987	34	174	51 25-50/70
35	.500000	35	1.000000	35	180	00 00000000
36	.544820	36	.997987	36	185	8 34-20/70
37	.589278	37	.991965	37	190	17 8-40/70
38	.633018	38	.981981	38	195	25 42-60/70
39	.675687	39	.968117	39	200	34 17-10/70
40	.716942	40	.950484	40	205	42 51-30/70
41	.756450	41	.929224	41	210	51 25-50/70
42	.793893	42	.904509	42	216	00 00000000
43	.828969	43	.876536	43	221	8 34-20/70
44	.861397	44	.845531	44	226	17 8-40/70
45	.890916	45	.811745	45	231	25 42-60/70
46	.917287	46	.775449	46	236	34 17-10/70
47	.940298	47	.736934	47	241	42 51-30/70
48	.959764	48	.696513	48	246	51 25-50/70
49	.975528	49	.654509	49	252	00 00000000
50	.987464	50	.611261	50	257	8 34-20/70
51	.995475	51	.567117	51	262	17 8-40/70
52	.999497	52	.522433	52	267	25 42-60/70
53	.999497	53	.477567	53	272	34 17-10/70
54	.995475	54	.432883	54	277	42 51-30/70
55	.987464	55	.388740	55	282	51 25-50/70
56	.975528	56	.345492	56	288	00 00000000
57	.959764	57	.303488	57	293	8 34-20/70
58	.940298	58	.263066	58	298	17 8-40/70
59	.917287	59	.224552	59	303	25 42-60/70
60	.890916	60	.188255	60	308	34 17-10/70
61	.861397	61	.154469	61	313	42 51-30/70
62	.828969	62	.123464	62	318	51 25-50/70
63	.793893	63	.095492	63	324	00 00000000
64	.756450	64	.070776	64	329	8 34-20/70
65	.716942	65	.049516	65	334	17 8-40/70
66	.675687	66	.031883	66	339	25 42-60/70
67	.633018	67	.018019	67	344	34 17-10/70
68	.589278	68	.008035	68	349	42 51-30/70
69	.544820	69	.002013	69	354	51 25-50/70
70	.500000	70	.000000	70	360	0 0

# 71 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

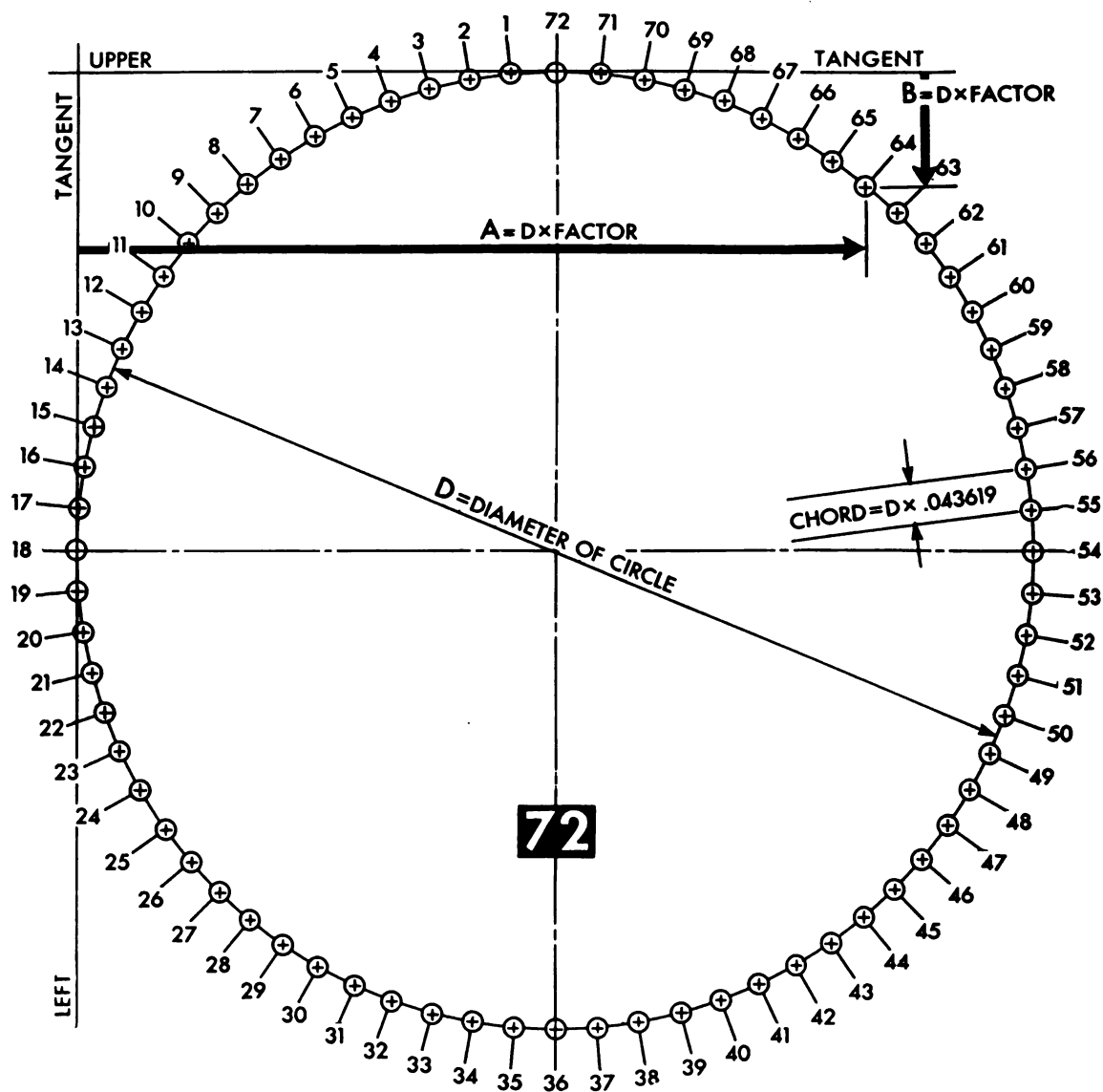


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.455810	1	.001957	1	5	4 13-37/71
2		.411966	2	.007811	2	10	8 27- 3/71
3		.368811	3	.017518	3	15	12 40-40/71
4		.326682	4	.031000	4	20	16 54- 6/71
5		.285910	5	.048153	5	25	21 7-43/71
6		.246814	6	.068843	6	30	25 21- 9/71
7		.209699	7	.092907	7	35	29 34-46/71
8		.174856	8	.120157	8	40	33 48-12/71
9		.142557	9	.150379	9	45	38 1-49/71
10		.113057	10	.183338	10	50	42 15-15/71
11		.086584	11	.218775	11	55	46 28-52/71
12		.063347	12	.256414	12	60	50 42-18/71
13		.043528	13	.295958	13	65	54 55-55/71
14		.027281	14	.337100	14	70	59 9-21/71

# COORDINATE FACTORS AND ANGLES—71 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.014733	15	.379516	15	76	3 22-58/71
16	.005984	16	.422876	16	81	7 36-24/71
17	.001101	17	.466839	17	86	11 49-61/71
18	.000122	18	.511061	18	91	16 3-27/71
19	.003056	19	.555196	19	96	20 16-64/71
20	.009879	20	.598901	20	101	24 30-30/71
21	.020538	21	.641831	21	106	28 43-67/71
22	.034949	22	.683651	22	111	32 57-33/71
23	.053000	23	.724033	23	116	37 10-70/71
24	.074549	24	.762663	24	121	41 24-36/71
25	.099428	25	.799236	25	126	45 38- 2/71
26	.127442	26	.833468	26	131	49 51-39/71
27	.158372	27	.865090	27	136	54 5- 5/71
28	.191976	28	.893854	28	141	58 18-42/71
29	.227990	29	.919536	29	147	2 32- 8/71
30	.266133	30	.941935	30	152	6 45-45/71
31	.306106	31	.960874	31	157	10 59-11/71
32	.347597	32	.976207	32	162	15 12-48/71
33	.390281	33	.987813	33	167	19 26-14/71
34	.433823	34	.995601	34	172	23 39-51/71
35	.477883	35	.999511	35	177	27 53-17/71
36	.522117	36	.999511	36	182	32 6-54/71
37	.566177	37	.995601	37	187	36 20-20/71
38	.609719	38	.987813	38	192	40 33-57/71
39	.652403	39	.976207	39	197	44 47-23/71
40	.693894	40	.960874	40	202	49 00-60/71
41	.733868	41	.941935	41	207	53 14-26/71
42	.772010	42	.919536	42	212	57 27-63/71
43	.808024	43	.893854	43	218	1 41-29/71
44	.841628	44	.865090	44	223	5 54-66/71
45	.872558	45	.833468	45	228	10 8-32/71
46	.900572	46	.799236	46	233	14 21-69/71
47	.925451	47	.762663	47	238	18 35-35/71
48	.947000	48	.724033	48	243	22 49- 1/71
49	.965051	49	.683651	49	248	27 2-38/71
50	.979462	50	.641831	50	253	31 16- 4/71
51	.990121	51	.598901	51	258	35 29-41/71
52	.996944	52	.555196	52	263	39 43- 7/71
53	.999878	53	.511061	53	268	43 56-44/71
54	.998899	54	.466839	54	273	48 10-10/71
55	.994016	55	.422876	55	278	52 23-47/71
56	.985267	56	.379516	56	283	56 37-13/71
57	.972719	57	.337100	57	289	00 50-50/71
58	.956472	58	.295958	58	294	5 4-16/71
59	.936653	59	.256414	59	299	9 17-53/71
60	.913416	60	.218775	60	304	13 31-19/71
61	.886944	61	.183338	61	309	17 44-56/71
62	.857443	62	.150379	62	314	21 58-22/71
63	.825144	63	.120157	63	319	26 11-59/71
64	.790301	64	.092907	64	324	30 25-25/71
65	.753187	65	.068843	65	329	34 38-62/71
66	.714090	66	.048153	66	334	38 52-28/71
67	.673318	67	.031000	67	339	43 5-65/71
68	.631190	68	.017518	68	344	47 19-31/71
69	.588034	69	.007811	69	349	51 32-68/71
70	.544190	70	.001957	70	354	55 46-34/71
71	.500000	71	.000000	71	360	0 0

# 72 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.456422	1	.001903	1	5	0
2		.413176	2	.007596	2	10	0
3		.370591	3	.017037	3	15	0
4		.328990	4	.030154	4	20	0
5		.288691	5	.046846	5	25	0
6		.250000	6	.066987	6	30	0
7		.213212	7	.090424	7	35	0
8		.178606	8	.116978	8	40	0
9		.146447	9	.146447	9	45	0
10		.116978	10	.178606	10	50	0
11		.090424	11	.213212	11	55	0
12		.066987	12	.250000	12	60	0
13		.046846	13	.288691	13	65	0
14		.030154	14	.328990	14	70	0

# COORDINATE FACTORS AND ANGLES—72 HOLE DIVISION

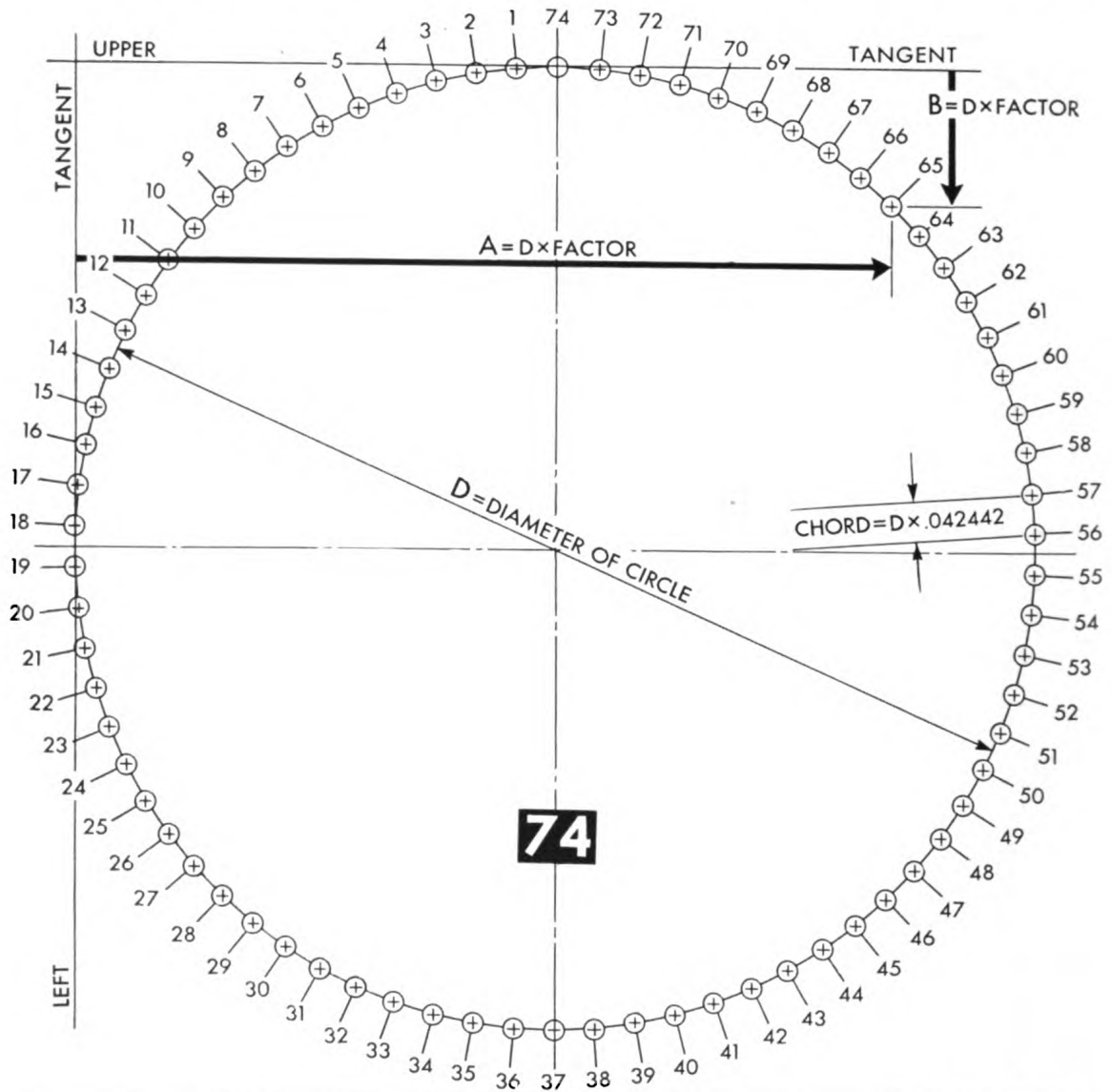
	→ FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.017037	15	.370591	15	75	0
16	.007596	16	.413176	16	80	0
17	.001903	17	.456422	17	85	0
18	.000000	18	.500000	18	90	0
19	.001903	19	.543578	19	95	0
20	.007596	20	.586824	20	100	0
21	.017037	21	.629410	21	105	0
22	.030154	22	.671010	22	110	0
23	.046846	23	.711309	23	115	0
24	.066987	24	.750000	24	120	0
25	.090424	25	.786788	25	125	0
26	.116978	26	.821394	26	130	0
27	.146447	27	.853553	27	135	0
28	.178606	28	.883022	28	140	0
29	.213212	29	.909576	29	145	0
30	.250000	30	.933013	30	150	0
31	.288691	31	.953154	31	155	0
32	.328990	32	.969846	32	160	0
33	.370591	33	.982963	33	165	0
34	.413176	34	.992404	34	170	0
35	.456422	35	.998097	35	175	0
36	.500000	36	1.000000	36	180	0
37	.543578	37	.998097	37	185	0
38	.586824	38	.992404	38	190	0
39	.629410	39	.982963	39	195	0
40	.671010	40	.969846	40	200	0
41	.711309	41	.953154	41	205	0
42	.750000	42	.933013	42	210	0
43	.786788	43	.909576	43	215	0
44	.821394	44	.883022	44	220	0
45	.853553	45	.853553	45	225	0
46	.883022	46	.821394	46	230	0
47	.909576	47	.786788	47	235	0
48	.933013	48	.750000	48	240	0
49	.953154	49	.711309	49	245	0
50	.969846	50	.671010	50	250	0
51	.982963	51	.629410	51	255	0
52	.992404	52	.586824	52	260	0
53	.998097	53	.543578	53	265	0
54	1.000000	54	.500000	54	270	0
55	.998097	55	.456422	55	275	0
56	.992404	56	.413176	56	280	0
57	.982963	57	.370591	57	285	0
58	.969846	58	.328990	58	290	0
59	.953154	59	.288691	59	295	0
60	.933013	60	.250000	60	300	0
61	.909576	61	.213212	61	305	0
62	.883022	62	.178606	62	310	0
63	.853553	63	.146447	63	315	0
64	.821394	64	.116978	64	320	0
65	.786788	65	.090424	65	325	0
66	.750000	66	.066987	66	330	0
67	.711309	67	.046846	67	335	0
68	.671010	68	.030154	68	340	0
69	.629410	69	.017037	69	345	0
70	.586824	70	.007596	70	350	0
71	.543578	71	.001903	71	355	0
72	.500000	72	.000000	72	360	0

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# COORDINATE FACTORS AND ANGLES—73 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
16		.009347	16	.403774	16	78	54 14-58/73
17		.002891	17	.446309	17	83	50 8-16/73
18		.000116	18	.489242	18	88	46 1-47/73
19		.001041	19	.532254	19	93	41 55- 5/73
20		.005661	20	.575028	20	98	37 48-36/73
21		.013941	21	.617246	21	103	33 41-67/73
22		.025819	22	.658595	22	108	29 35-25/73
23		.041208	23	.698771	23	113	25 28-56/73
24		.059994	24	.737476	24	118	21 22-14/73
25		.082037	25	.774421	25	123	17 15-45/73
26		.107175	26	.809336	26	128	13 9- 3/73
27		.135221	27	.841960	27	133	9 2-34/73
28		.165968	28	.872052	28	138	4 55 65/73
29		.199188	29	.899390	29	143	00 49-23/73
30		.234635	30	.923770	30	147	56 42-54/73
31		.272047	31	.945014	31	152	52 36-12/73
32		.311146	32	.962962	32	157	48 29-43/73
33		.351644	33	.977483	33	162	44 23- 1/73
34		.393240	34	.988469	34	167	40 16-32/73
35		.435626	35	.995839	35	172	36 9-63/73
36		.478489	36	.999537	36	177	32 3-21/73
37		.521511	37	.999537	37	182	27 56-52/73
38		.564374	38	.995839	38	187	23 50-10/73
39		.606760	39	.988469	39	192	19 43-41/73
40		.648356	40	.977483	40	197	15 36-72/73
41		.688854	41	.962962	41	202	11 30-30/73
42		.727953	42	.945014	42	207	7 23-61/73
43		.765365	43	.923770	43	212	3 17-19/73
44		.800812	44	.899390	44	216	59 10-50/73
45		.834032	45	.872052	45	221	55 4- 8/73
46		.864779	46	.841960	46	226	50 57-39/73
47		.892825	47	.809336	47	231	46 50-70/73
48		.917963	48	.774421	48	236	42 44-28/73
49		.940006	49	.737476	49	241	38 37-59/73
50		.958792	50	.698771	50	246	34 31-17/73
51		.974181	51	.658595	51	251	30 24-48/73
52		.986059	52	.617246	52	256	26 18- 6/73
53		.994339	53	.575028	53	261	22 11-37/73
54		.998959	54	.532254	54	266	18 4-68/73
55		.999884	55	.489242	55	271	13 58-26/73
56		.997109	56	.446309	56	276	9 51-57/73
57		.990653	57	.403774	57	281	5 45-15/73
58		.980565	58	.361952	58	286	1 38-46/73
59		.966919	59	.321151	59	290	57 32- 4/73
60		.949815	60	.281674	60	295	53 25-35/73
61		.929382	61	.243814	61	300	49 18-66/73
62		.905770	62	.207851	62	305	45 12-24/73
63		.879153	63	.174051	63	310	41 5-55/73
64		.849728	64	.142663	64	315	36 59-13/73
65		.817716	65	.113922	65	320	32 52-44/73
66		.783351	66	.088038	66	325	28 46- 2/73
67		.746888	67	.065205	67	330	24 39-33/73
68		.708597	68	.045591	68	335	20 32-64/73
69		.668761	69	.029341	69	340	16 26-22/73
70		.627677	70	.016576	70	345	12 19-53/73
71		.585647	71	.007390	71	350	8 13-11/73
72		.542982	72	.001851	72	355	4 6-42/73
73		.500000	73	.000000	73	360	0 0

# 74 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

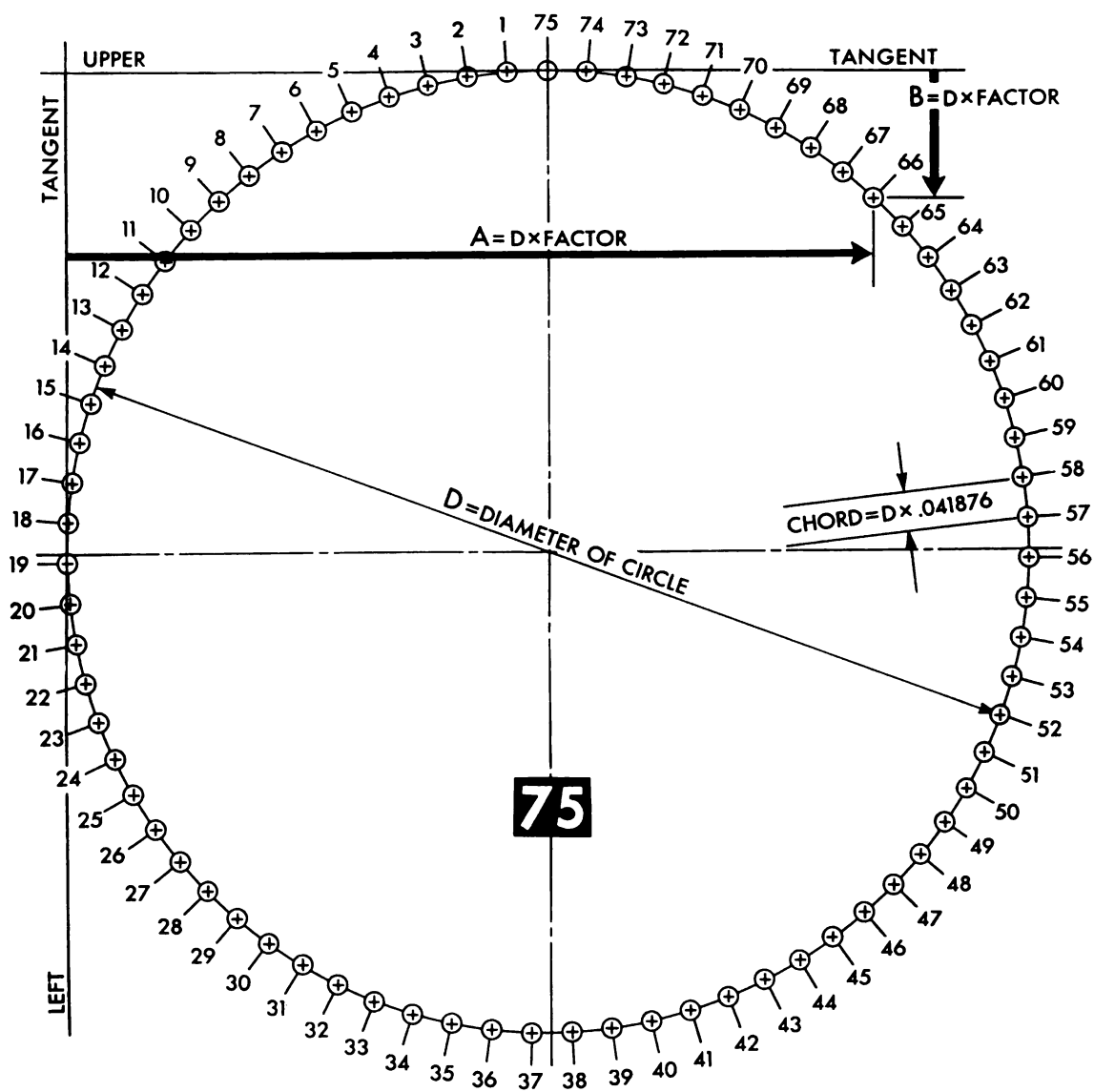


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.457597	1	.001801	1	4	51	53-38/74
2	.415500	2	.007192	2	9	43	47- 2/74
3	.374011	3	.016134	3	14	35	40-40/74
4	.333430	4	.028561	4	19	27	34- 4/74
5	.294049	5	.044386	5	24	19	27-42/74
6	.256153	6	.063493	6	29	11	21- 6/74
7	.220013	7	.085745	7	34	3	14-44/74
8	.185890	8	.110982	8	38	55	8- 8/74
9	.154031	9	.139022	9	43	47	1-46/74
10	.124664	10	.169661	10	48	38	55-10/74
11	.098001	11	.202683	11	53	30	48-48/74
12	.074235	12	.237846	12	58	22	42-12/74
13	.053537	13	.274898	13	63	14	35-50/74
14	.036055	14	.313572	14	68	6	29-14/74
15	.021917	15	.353589	15	72	58	22-52/74

# COORDINATE FACTORS AND ANGLES—74 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
16		.011222	16	.394660	16	77	50 16-16/74
17		.004050	17	.436491	17	82	42 9-54/74
18		.000451	18	.478779	18	87	34 3-18/74
19		.000451	19	.521221	19	92	25 56-56/74
20		.004050	20	.563509	20	97	17 50-20/74
21		.011222	21	.605340	21	102	9 43-58/74
22		.021917	22	.646411	22	107	1 37-22/74
23		.036055	23	.686428	23	111	53 30-60/74
24		.053537	24	.725102	24	116	45 24-24/74
25		.074235	25	.762154	25	121	37 17-62/74
26		.098001	26	.797317	26	126	29 11-26/74
27		.124664	27	.830339	27	131	21 4-64/74
28		.154031	28	.860978	28	136	12 58-28/74
29		.185890	29	.889018	29	141	4 51-66/74
30		.220013	30	.914255	30	145	56 45-30/74
31		.256153	31	.936507	31	150	48 38-68/74
32		.294049	32	.955614	32	155	40 32-32/74
33		.333430	33	.971439	33	160	32 25-70/74
34		.374011	34	.983866	34	165	24 19-34/74
35		.415500	35	.992808	35	170	16 12-72/74
36		.457597	36	.998199	36	175	8 6-36/74
37		.500000	37	1.000000	37	180	00 00000000
38		.542403	38	.998199	38	184	51 53-38/74
39		.584500	39	.992808	39	189	43 47-2/74
40		.625989	40	.983866	40	194	35 40-40/74
41		.666570	41	.971439	41	199	27 34-4/74
42		.705951	42	.955614	42	204	19 27-42/74
43		.743847	43	.936507	43	209	11 21-6/74
44		.779987	44	.914255	44	214	3 14-44/74
45		.814110	45	.889018	45	218	55 8-8/74
46		.845969	46	.860978	46	223	47 1-46/74
47		.875336	47	.830339	47	228	38 55-10/74
48		.901999	48	.797317	48	233	30 48-48/74
49		.925765	49	.762154	49	238	22 42-12/74
50		.946463	50	.725102	50	243	14 35-50/74
51		.963945	51	.686428	51	248	6 29-14/74
52		.978083	52	.646411	52	252	58 22-52/74
53		.988778	53	.605340	53	257	50 16-16/74
54		.995950	54	.563509	54	262	42 9-54/74
55		.999549	55	.521221	55	267	34 3-18/74
56		.999549	56	.478779	56	272	25 56-56/74
57		.995950	57	.436491	57	277	17 50-20/74
58		.988778	58	.394660	58	282	9 43-58/74
59		.978083	59	.353589	59	287	1 37-22/74
60		.963945	60	.313572	60	291	53 30-60/74
61		.946463	61	.274898	61	296	45 24-24/74
62		.925765	62	.237846	62	301	37 17-62/74
63		.901999	63	.202683	63	306	29 11-26/74
64		.875336	64	.169661	64	311	21 4-64/74
65		.845969	65	.139022	65	316	12 58-28/74
66		.814110	66	.110982	66	321	4 51-66/74
67		.779987	67	.085745	67	325	56 45-30/74
68		.743847	68	.063493	68	330	48 38-68/74
69		.705951	69	.044386	69	335	40 32-32/74
70		.666570	70	.028561	70	340	32 25-70/74
71		.625989	71	.016134	71	345	24 19-34/74
72		.584500	72	.007192	72	350	16 12-72/74
73		.542403	73	.001801	73	355	8 6-36/74
74		.500000	74	.000000	74	360	0 0

# 75 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

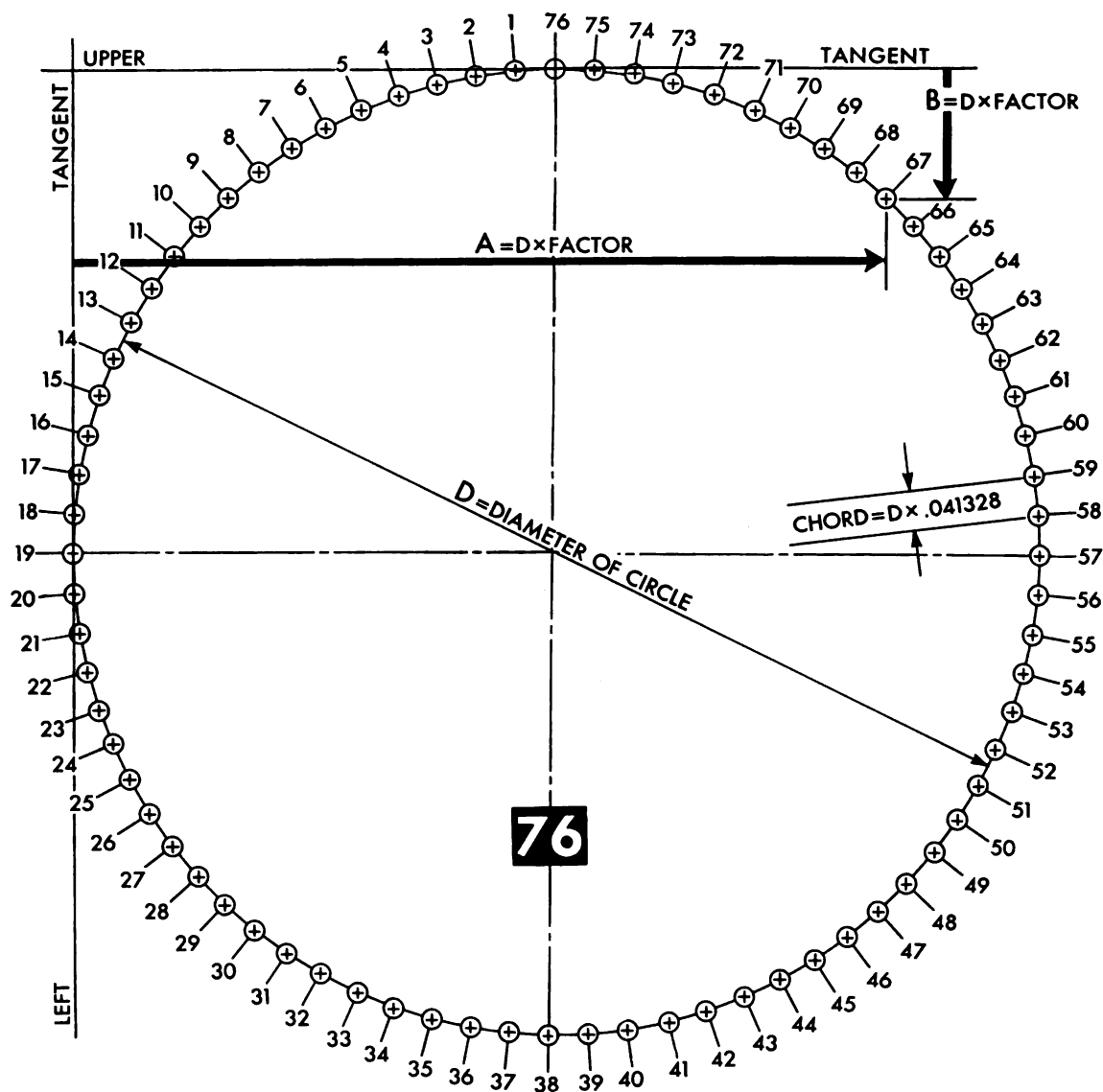


	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
1		.458161	1	.001754	1	4	48	0
2		.416616	2	.007002	2	9	36	0
3		.375655	3	.015708	3	14	24	0
4		.335567	4	.027812	4	19	12	0
5		.296632	5	.043227	5	24	00	0
6		.259123	6	.061847	6	28	48	0
7		.223304	7	.083539	7	33	36	0
8		.189426	8	.108153	8	38	24	0
9		.157726	9	.135516	9	43	12	0
10		.128428	10	.165435	10	48	00	0
11		.101735	11	.197700	11	52	48	0
12		.077836	12	.232087	12	57	36	0
13		.056898	13	.268352	13	62	24	0
14		.039068	14	.306242	14	67	12	0
15		.024472	15	.345492	15	72	00	0

# COORDINATE FACTORS AND ANGLES—75 HOLE DIVISION

	➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
16		.013211	16	.385825	16	76	48	0
17		.005364	17	.426958	17	81	36	0
18		.000987	18	.468605	18	86	24	0
19		.000110	19	.510471	19	91	12	0
20		.002739	20	.552264	20	96	00	0
21		.008856	21	.593691	21	100	48	0
22		.018419	22	.634460	22	105	36	0
23		.031359	23	.674286	23	110	24	0
24		.047586	24	.712890	24	115	12	0
25		.066987	25	.750000	25	120	00	0
26		.089425	26	.785357	26	124	48	0
27		.114743	27	.818712	27	129	36	0
28		.142764	28	.849832	28	134	24	0
29		.173290	29	.878498	29	139	12	0
30		.206107	30	.904508	30	144	00	0
31		.240987	31	.927682	31	148	48	0
32		.277682	32	.947856	32	153	36	0
33		.315938	33	.964888	33	158	24	0
34		.355484	34	.978660	34	163	12	0
35		.396044	35	.989074	35	168	00	0
36		.437333	36	.996057	36	172	48	0
37		.479062	37	.999561	37	177	36	0
38		.520938	38	.999561	38	182	24	0
39		.562667	39	.996057	39	187	12	0
40		.603956	40	.989074	40	192	00	0
41		.644516	41	.978660	41	196	48	0
42		.684062	42	.964888	42	201	36	0
43		.722318	43	.947856	43	206	24	0
44		.759014	44	.927682	44	211	12	0
45		.793893	45	.904508	45	216	00	0
46		.826710	46	.878498	46	220	48	0
47		.857236	47	.849832	47	225	36	0
48		.885257	48	.818712	48	230	24	0
49		.910575	49	.785357	49	235	12	0
50		.933013	50	.750000	50	240	00	0
51		.952414	51	.712890	51	244	48	0
52		.968641	52	.674286	52	249	36	0
53		.981581	53	.634460	53	254	24	0
54		.991144	54	.593691	54	259	12	0
55		.997261	55	.552264	55	264	00	0
56		.999890	56	.510471	56	268	48	0
57		.999013	57	.468605	57	273	36	0
58		.994636	58	.426958	58	278	24	0
59		.986789	59	.385825	59	283	12	0
60		.975528	60	.345492	60	288	00	0
61		.960932	61	.306242	61	292	48	0
62		.943102	62	.268352	62	297	36	0
63		.922164	63	.232087	63	302	24	0
64		.898265	64	.197700	64	307	12	0
65		.871572	65	.165435	65	312	00	0
66		.842274	66	.135516	66	316	48	0
67		.810574	67	.108153	67	321	36	0
68		.776696	68	.083539	68	326	24	0
69		.740877	69	.061847	69	331	12	0
70		.703368	70	.043227	70	336	00	0
71		.664433	71	.027812	71	340	48	0
72		.624345	72	.015708	72	345	36	0
73		.583384	73	.007002	73	350	24	0
74		.541839	74	.001754	74	355	12	0
75		.500000	75	.000000	75	360	0	0

# 76 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

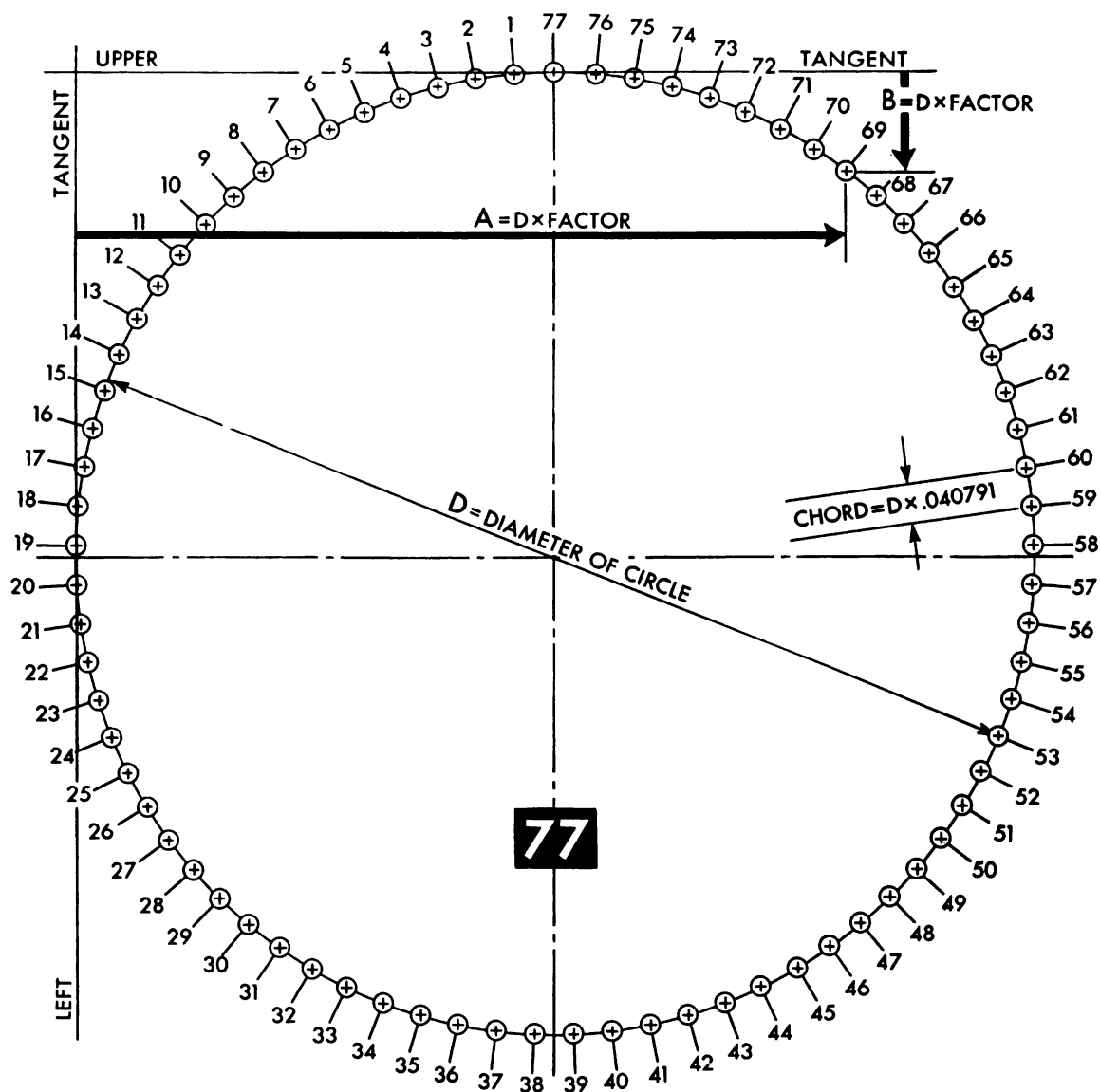


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.458710	1	.001708	1	4	44	12-48/76
2	.417703	2	.006819	2	9	28	25-20/76
3	.377257	3	.015300	3	14	12	37-68/76
4	.337650	4	.027091	4	18	56	50-40/76
5	.299152	5	.042113	5	23	41	3-12/76
6	.262026	6	.060263	6	28	25	15-60/76
7	.226526	7	.081417	7	33	9	28-32/76
8	.192894	8	.105430	8	37	53	41-4/76
9	.161359	9	.132138	9	42	37	53-52/76
10	.132138	10	.161359	10	47	22	6-24/76
11	.105430	11	.192894	11	52	6	18-72/76
12	.081417	12	.226526	12	56	50	31-44/76
13	.060263	13	.262026	13	61	34	44-16/76
14	.042113	14	.299152	14	66	18	56-64/76
15	.027091	15	.337650	15	71	3	9-36/76

# COORDINATE FACTORS AND ANGLES—76 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
16		.015300	16	.377257	16	75	47 22- 8/76
17		.006819	17	.417703	17	80	31 34-56/76
18		.001708	18	.458710	18	85	15 47-28/76
19		.000000	19	.500000	19	90	00 00000000
20		.001708	20	.541290	20	94	44 12-48/76
21		.006819	21	.582297	21	99	28 25-20/76
22		.015300	22	.622743	22	104	12 37-68/76
23		.027091	23	.662350	23	108	56 50-40/76
24		.042113	24	.700848	24	113	41 3-12/76
25		.060263	25	.737974	25	118	25 15-60/76
26		.081417	26	.773474	26	123	9 28-32/76
27		.105430	27	.807106	27	127	53 41- 4/76
28		.132138	28	.838641	28	132	37 53-52/76
29		.161359	29	.867862	29	137	22 6-24/76
30		.192894	30	.894570	30	142	6 18-72/76
31		.226526	31	.918583	31	146	50 31-44/76
32		.262026	32	.939737	32	151	34 44-16/76
33		.299152	33	.957887	33	156	18 56-64/76
34		.337650	34	.972909	34	161	3 9-36/76
35		.377257	35	.984700	35	165	47 22- 8/76
36		.417703	36	.993181	36	170	31 34-56/76
37		.458710	37	.998292	37	175	15 47-28/76
38		.500000	38	1.000000	38	180	00 00000000
39		.541290	39	.998292	39	184	44 12-48/76
40		.582297	40	.993181	40	189	28 25-20/76
41		.622743	41	.984700	41	194	12 37-68/76
42		.662350	42	.972909	42	198	56 50-40/76
43		.700848	43	.957887	43	203	41 3-12/76
44		.737974	44	.939737	44	208	25 15-60/76
45		.773474	45	.918583	45	213	9 28-32/76
46		.807106	46	.894570	46	217	53 41- 4/76
47		.838641	47	.867862	47	222	37 53-52/76
48		.867862	48	.838641	48	227	22 6-24/76
49		.894570	49	.807106	49	232	6 18-72/76
50		.918583	50	.773474	50	236	50 31-44/76
51		.939737	51	.737974	51	241	34 44-16/76
52		.957887	52	.700848	52	246	18 56-64/76
53		.972909	53	.662350	53	251	3 9-36/76
54		.984700	54	.622743	54	255	47 22- 8/76
55		.993181	55	.582297	55	260	31 34 56/76
56		.998292	56	.541290	56	265	15 47 28/76
57		1.000000	57	.500000	57	270	00 00000000
58		.998292	58	.458710	58	274	44 12 48/76
59		.993181	59	.417703	59	279	28 25-20/76
60		.984700	60	.377257	60	284	12 37-68/76
61		.972909	61	.337650	61	288	56 50-40/76
62		.957887	62	.299152	62	293	41 3-12/76
63		.939737	63	.262026	63	298	25 15-60/76
64		.918583	64	.226526	64	303	9 28-32/76
65		.894570	65	.192894	65	307	53 41- 4/76
66		.867862	66	.161359	66	312	37 53-52/76
67		.838641	67	.132138	67	317	22 6-24/76
68		.807106	68	.105430	68	322	6 18-72/76
69		.773474	69	.081417	69	326	50 31-44/76
70		.737974	70	.060263	70	331	34 44-16/76
71		.700848	71	.042113	71	336	18 56-64/76
72		.662350	72	.027091	72	341	3 9-36/76
73		.622743	73	.015300	73	345	47 22- 8/76
74		.582297	74	.006819	74	350	31 34-56/76
75		.541290	75	.001708	75	355	15 47-28/76
76		.500000	76	.000000	76	360	0 0

# 77 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

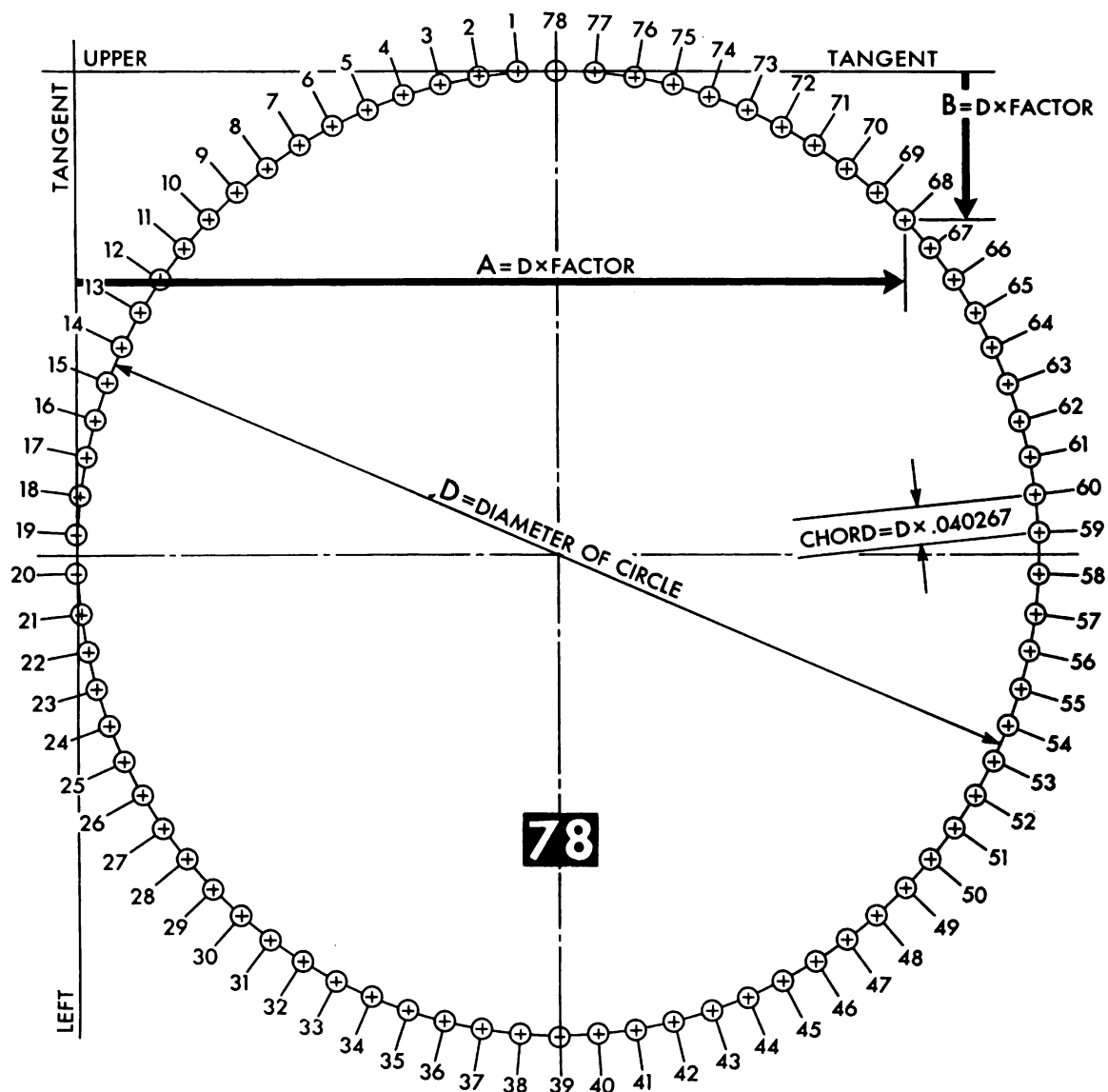


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	M.N.	SEC.
1	.459245	1	.001664	1	4	40	31-13/77
2	.418762	2	.006644	2	9	21	2-26/77
3	.378819	3	.014907	3	14	1	33-39/77
4	.339683	4	.026399	4	18	42	4-52/77
5	.301613	5	.041042	5	23	22	35-65/77
6	.264864	6	.058739	6	28	3	7- 1/77
7	.229680	7	.079373	7	32	43	38-14/77
8	.196294	8	.102806	8	37	24	9-27/77
9	.164930	9	.128883	9	42	4	40-40/77
10	.135795	10	.157429	10	46	45	11-53/77
11	.109084	11	.188255	11	51	25	42-66/77
12	.084975	12	.221156	12	56	6	14- 2/77
13	.063627	13	.255912	13	60	46	45-15/77
14	.045184	14	.292293	14	65	27	16-28/77
15	.029767	15	.330055	15	70	7	47-41/77
16	.017480	16	.368949	16	74	48	18-54/77

# COORDINATE FACTORS AND ANGLES—77 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
17		.008404		17	.408715	79	28	49-67/77
18		.002599		18	.449089	84	9	21- 3/77
19		.000104		19	.489801	88	49	52-16/77
20		.000936		20	.530581	93	30	23-29/77
21		.005089		21	.571157	98	10	54-42/77
22		.012536		22	.611260	102	51	25-55/77
23		.023227		23	.650623	107	31	56-68/77
24		.037090		24	.688983	112	12	28- 4/77
25		.054035		25	.726086	116	52	59-17/77
26		.073947		26	.761685	121	33	30-30/77
27		.096694		27	.795541	126	14	1-43/77
28		.122125		28	.827430	130	54	32-56/77
29		.150071		29	.857141	135	35	3-69/77
30		.180346		30	.884475	140	15	35- 5/77
31		.212748		31	.909251	144	56	6-18/77
32		.247061		32	.931303	149	36	37-31/77
33		.283058		33	.950484	154	17	8-44/77
34		.320499		34	.966668	158	57	39-57/77
35		.359134		35	.979746	163	38	10-70/77
36		.398706		36	.989632	168	18	42- 6/77
37		.438953		37	.996259	172	59	13-19/77
38		.479606		38	.999584	177	39	44-32/77
39		.520395		39	.999584	182	20	15-45/77
40		.561047		40	.996259	187	00	46-58/77
41		.601294		41	.989632	191	41	17-71/77
42		.640866		42	.979746	196	21	49- 7/77
43		.679501		43	.966668	201	2	20-20/77
44		.716942		44	.950484	205	42	51-33/77
45		.752939		45	.931303	210	23	22-46/77
46		.787252		46	.909251	215	3	53-59/77
47		.819654		47	.884475	219	44	24-72/77
48		.849929		48	.857141	224	24	56- 8/77
49		.877874		49	.827430	229	5	27-21/77
50		.903306		50	.795541	233	45	58-34/77
51		.926053		51	.761685	238	26	29-47/77
52		.945965		52	.726086	243	7	00-60/77
53		.962910		53	.688983	247	47	31-73/77
54		.976773		54	.650623	252	28	3- 9/77
55		.987464		55	.611260	257	8	34-22/77
56		.994911		56	.571157	261	49	5-35/77
57		.999064		57	.530581	266	29	36-48/77
58		.999896		58	.489801	271	10	7-61/77
59		.997401		59	.449089	275	50	38-74/77
60		.991596		60	.408715	280	31	10-10/77
61		.982520		61	.368949	285	11	41-23/77
62		.970233		62	.330055	289	52	12-36/77
63		.954816		63	.292293	294	32	43-49/77
64		.936373		64	.255912	299	13	14-62/77
65		.915025		65	.221156	303	53	45-75/77
66		.890916		66	.188255	308	34	17-11/77
67		.864205		67	.157429	313	14	48-24/77
68		.835070		68	.128883	317	55	19-37/77
69		.803706		69	.102806	322	35	50-50/77
70		.770320		70	.079373	327	16	21-63/77
71		.735136		71	.058739	331	56	52-76/77
72		.698387		72	.041042	336	37	24-12/77
73		.660317		73	.026399	341	17	55-25/77
74		.621181		74	.014907	345	58	26-38/77
75		.581238		75	.006644	350	38	57-51/77
76		.540755		76	.001664	355	19	28-64/77
77		.500000		77	.000000	360	0	0

# 78 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

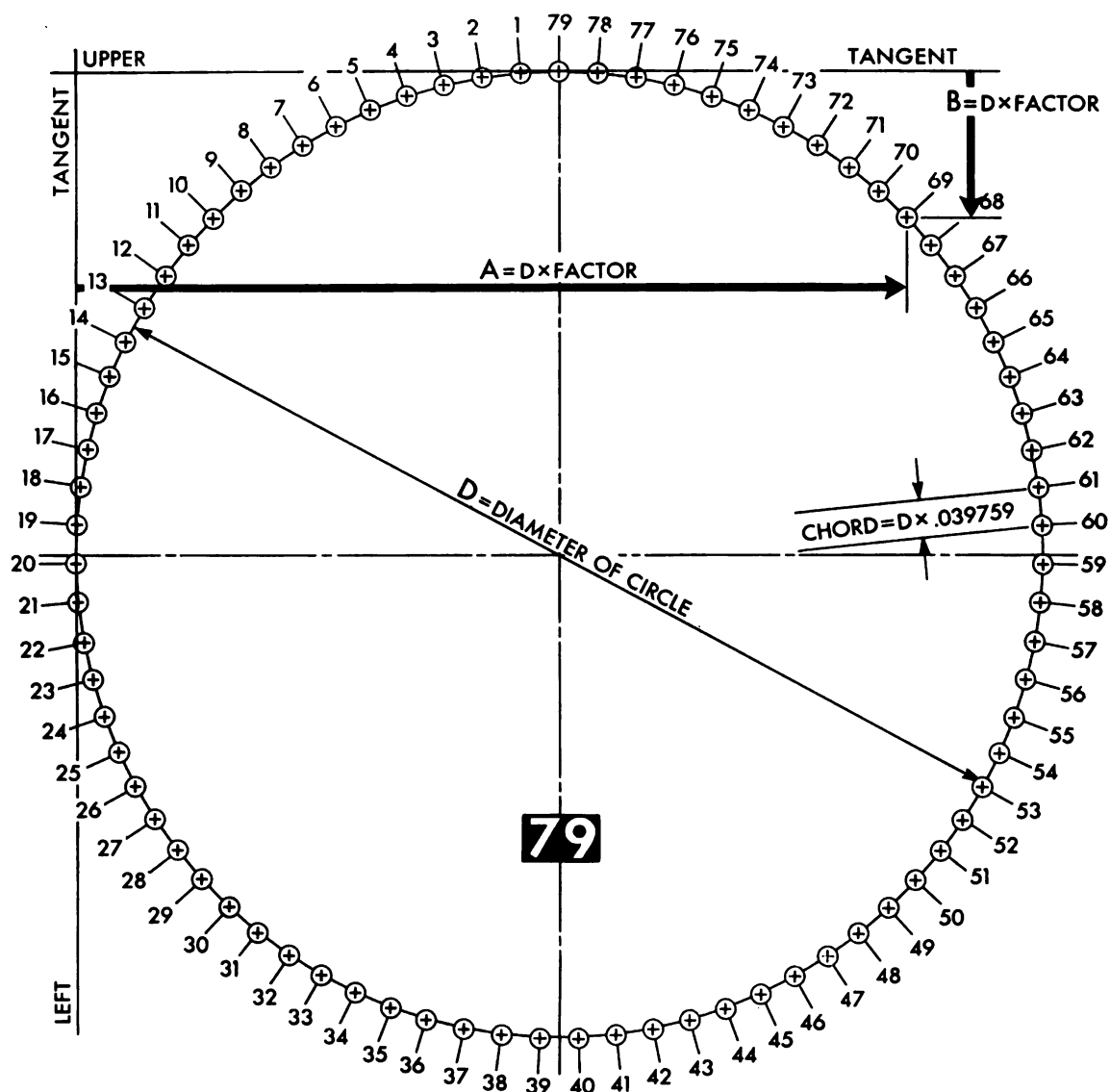


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.459767	1	.001621	1	4	36 55-30/78
2		.419794	2	.006475	2	9	13 50-60/78
3		.380342	3	.014529	3	13	50 46-12/78
4		.341666	4	.025732	4	18	27 41-42/78
5		.304017	5	.040010	5	23	4 36-72/78
6		.267638	6	.057272	6	27	41 32-24/78
7		.232767	7	.077405	7	32	18 27-54/78
8		.199629	8	.100279	8	36	55 23- 6/78
9		.168439	9	.125745	9	41	32 18-36/78
10		.139399	10	.153638	10	46	9 13-66/78
11		.112698	11	.183777	11	50	46 9-18/78
12		.088508	12	.215968	12	55	23 4-48/78
13		.066987	13	.250000	13	60	00 0000000
14		.048275	14	.285654	14	64	36 55-30/78
15		.032492	15	.322698	15	69	13 50-60/78
16		.019741	16	.360891	16	73	50 46-12/78

# COORDINATE FACTORS AND ANGLES—78 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
17	.010105	17	.399987	17	78	27 41-42/78
18	.003646	18	.439732	18	83	4 36-72/78
19	.000406	19	.479867	19	87	41 32-24/78
20	.000406	20	.520133	20	92	18 27-54/78
21	.003646	21	.560268	21	96	55 23- 6/78
22	.010105	22	.600013	22	101	32 18-36/78
23	.019741	23	.639109	23	106	9 13-66/78
24	.032492	24	.677302	24	110	46 9-18/78
25	.048275	25	.714346	25	115	23 4-48/78
26	.066987	26	.750000	26	120	00 00000000
27	.088508	27	.784032	27	124	36 55-30/78
28	.112698	28	.816223	28	129	13 50-60/78
29	.139399	29	.846362	29	133	50 46-12/78
30	.168439	30	.874255	30	138	27 41-42/78
31	.199629	31	.899721	31	143	4 36-72/78
32	.232767	32	.922595	32	147	41 32-24/78
33	.267638	33	.942728	33	152	18 27-54/78
34	.304017	34	.959990	34	156	55 23- 6/78
35	.341666	35	.974268	35	161	32 18-36/78
36	.380342	36	.985471	36	166	9 13-66/78
37	.419794	37	.993525	37	170	46 9-18/78
38	.459767	38	.998379	38	175	23 4-48/78
39	.500000	39	1.000000	39	180	00 00000000
40	.540233	40	.998379	40	184	36 55-30/78
41	.580206	41	.993525	41	189	13 50-60/78
42	.619658	42	.985471	42	193	50 46-12/78
43	.658334	43	.974268	43	198	27 41-42/78
44	.695983	44	.959990	44	203	4 36-72/78
45	.732362	45	.942728	45	207	41 32-24/78
46	.767233	46	.922595	46	212	18 27-54/78
47	.800371	47	.899721	47	216	55 23- 6/78
48	.831561	48	.874255	48	221	32 18-36/78
49	.860601	49	.846362	49	226	9 13-66/78
50	.887302	50	.816223	50	230	46 9-18/78
51	.911492	51	.784032	51	235	23 4-48/78
52	.933013	52	.750000	52	240	00 00000000
53	.951725	53	.714346	53	244	36 55-30/78
54	.967508	54	.677302	54	249	13 50-60/78
55	.980259	55	.639109	55	253	50 46-12/78
56	.989895	56	.600013	56	258	27 41-42/78
57	.996354	57	.560268	57	263	4 36-72/78
58	.999595	58	.520133	58	267	41 32-24/78
59	.999595	59	.479867	59	272	18 27-54/78
60	.996354	60	.439732	60	276	55 23- 6/78
61	.989895	61	.399987	61	281	32 18-36/78
62	.980259	62	.360891	62	286	9 13-66/78
63	.967508	63	.322698	63	290	46 9-18/78
64	.951725	64	.285654	64	295	23 4-48/78
65	.933013	65	.250000	65	300	00 00000000
66	.911492	66	.215968	66	304	36 55-30/78
67	.887302	67	.183777	67	309	13 50-60/78
68	.860601	68	.153638	68	313	50 46-12/78
69	.831561	69	.125745	69	318	27 41-42/78
70	.800371	70	.100279	70	323	4 36-72/78
71	.767233	71	.077405	71	327	41 32-24/78
72	.732362	72	.057272	72	332	18 27-54/78
73	.695983	73	.040010	73	336	55 23- 6/78
74	.658334	74	.025732	74	341	32 18-36/78
75	.619658	75	.014529	75	346	9 13-66/78
76	.580206	76	.006475	76	350	46 9-18/78
77	.540233	77	.001621	77	355	23 4-48/78
78	.500000	78	.000000	78	360	0 0

# 79 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

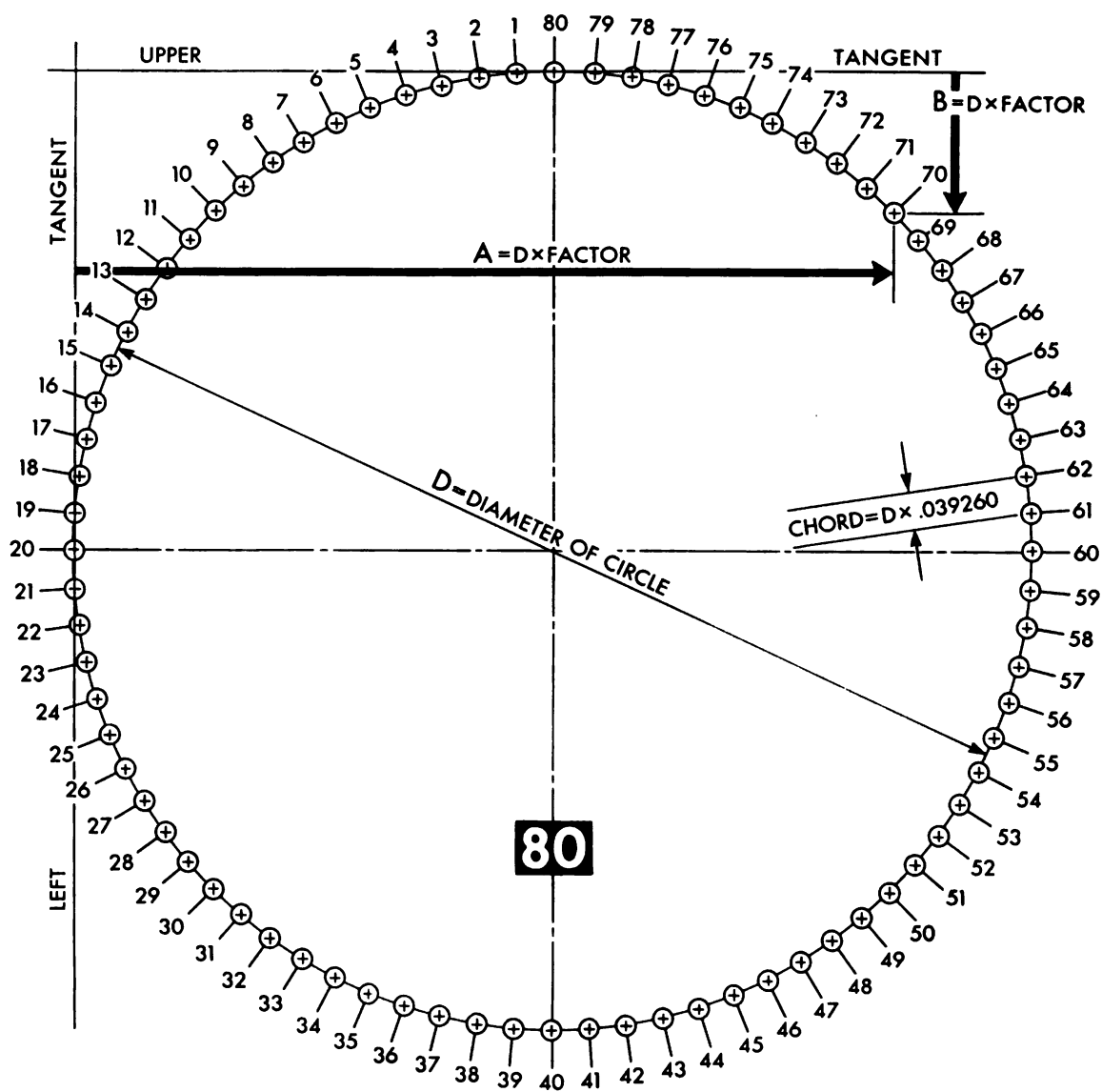


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.460275	1	.001581	1	4	33 25- 5/79
2		.420801	2	.006312	2	9	6 50-10/79
3		.381828	3	.014165	3	13	40 15-15/79
4		.343602	4	.025090	4	18	13 40-20/79
5		.306364	5	.039017	5	22	47 5-25/79
6		.270351	6	.055858	6	27	20 30-30/79
7		.235790	7	.075508	7	31	53 55-35/79
8		.202899	8	.097842	8	36	27 20-40/79
9		.171887	9	.122718	9	41	00 45-45/79
10		.142949	10	.149979	10	45	34 10-50/79
11		.116269	11	.179453	11	50	7 35-55/79
12		.092014	12	.210954	12	54	41 00-60/79
13		.070339	13	.244282	13	59	14 25-65/79
14		.051381	14	.279227	14	63	47 50-70/79
15		.035258	15	.315568	15	68	21 15-75/79
16		.022074	16	.353075	16	72	54 41- 1/79

# COORDINATE FACTORS AND ANGLES—79 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
17	.011912	17	.391511	17	77	28	6- 6/79
18	.004835	18	.430632	18	82	1	31-11/79
19	.000889	19	.470192	19	86	34	56-16/79
20	.000099	20	.509941	20	91	8	21-21/79
21	.002469	21	.549627	21	95	41	46-26/79
22	.007985	22	.588999	22	100	15	11-31/79
23	.016611	23	.627808	23	104	48	36-36/79
24	.028293	24	.665810	24	109	22	1-41/79
25	.042958	25	.702763	25	113	55	26-46/79
26	.060512	26	.738434	26	118	28	51-51/79
27	.080845	27	.772597	27	123	2	16-56/79
28	.103828	28	.805038	28	127	35	41-61/79
29	.129316	29	.835549	29	132	9	6-66/79
30	.157147	30	.863939	30	136	42	31-71/79
31	.187146	31	.890029	31	141	15	56-76/79
32	.219123	32	.913652	32	145	49	22- 2/79
33	.252875	33	.934660	33	150	22	47- 7/79
34	.288190	34	.952920	34	154	56	12-12/79
35	.324845	35	.968317	35	159	29	37-17/79
36	.362606	36	.980752	36	164	3	2-22/79
37	.401236	37	.990149	37	168	36	27-27/79
38	.440491	38	.996446	38	173	9	52-32/79
39	.480122	39	.999605	39	177	43	17-37/79
40	.519878	40	.999605	40	182	16	42-42/79
41	.559509	41	.996446	41	186	50	7-47/79
42	.598764	42	.990149	42	191	23	32-52/79
43	.637394	43	.980752	43	195	56	57-57/79
44	.675155	44	.968317	44	200	30	22-62/79
45	.711810	45	.952920	45	205	3	47-67/79
46	.747125	46	.934660	46	209	37	12-72/79
47	.780877	47	.913652	47	214	10	37-77/79
48	.812854	48	.890029	48	218	44	3- 3/79
49	.842853	49	.863939	49	223	17	28- 8/79
50	.870684	50	.835549	50	227	50	53-13/79
51	.896172	51	.805038	51	232	24	18-18/79
52	.919155	52	.772597	52	236	57	43-23/79
53	.939488	53	.738434	53	241	31	8- 28/79
54	.957042	54	.702763	54	246	4	33-33/79
55	.971707	55	.665810	55	250	37	58-38/79
56	.983389	56	.627808	56	255	11	23-43/79
57	.992015	57	.588999	57	259	44	48-48/79
58	.997531	58	.549627	58	264	18	13-53/79
59	.999901	59	.509941	59	268	51	38-58/79
60	.999111	60	.470192	60	273	25	3- 63/79
61	.995165	61	.430632	61	277	58	28-68/79
62	.988088	62	.391511	62	282	31	53-73/79
63	.977926	63	.353075	63	287	5	18-78/79
64	.964742	64	.315568	64	291	38	44- 4/79
65	.948619	65	.279227	65	296	12	9- 9/79
66	.929661	66	.244282	66	300	45	34-14/79
67	.907986	67	.210954	67	305	18	59-19/79
68	.883731	68	.179453	68	309	52	24-24/79
69	.857051	69	.149979	69	314	25	49-29/79
70	.828113	70	.122718	70	318	59	14-34/79
71	.797101	71	.097842	71	323	32	39-39/79
72	.764210	72	.075508	72	328	6	4-44/79
73	.729649	73	.055858	73	332	39	29-49/79
74	.693636	74	.039017	74	337	12	54-54/79
75	.656398	75	.025090	75	341	46	19-59/79
76	.618172	76	.014165	76	346	19	44-64/79
77	.579199	77	.006312	77	350	53	9-69/79
78	.539725	78	.001581	78	355	26	34-74/79
79	.500000	79	.000000	79	360	0	0

# 80 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

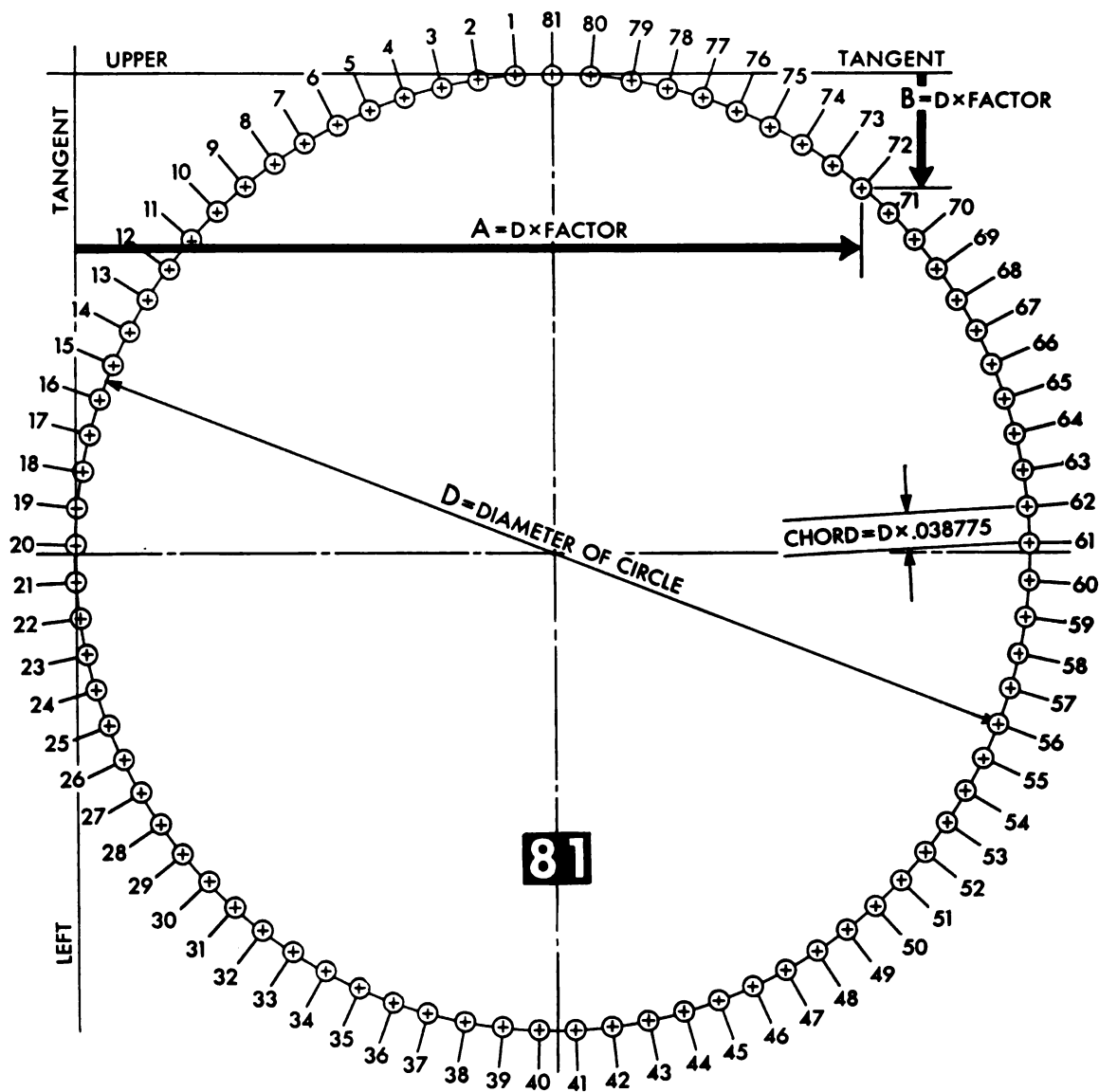


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.460770	1	.001541	1	4	30
2	.421783	2	.006156	2	9	00
3	.383277	3	.013815	3	13	30
4	.345492	4	.024472	4	18	00
5	.308658	5	.038060	5	22	30
6	.273005	6	.054497	6	27	00
7	.238751	7	.073680	7	31	30
8	.206107	8	.095492	8	36	00
9	.175276	9	.119797	9	40	30
10	.146447	10	.146447	10	45	00
11	.119797	11	.175276	11	49	30
12	.095492	12	.206107	12	54	00
13	.073680	13	.238751	13	58	30
14	.054497	14	.273005	14	63	00
15	.038060	15	.308658	15	67	30
16	.024472	16	.345492	16	72	00
17	.013815	17	.383277	17	76	30

# COORDINATE FACTORS AND ANGLES—80 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
18	.006156	18	.421783	18	81	00
19	.001541	19	.460770	19	85	30
20	.000000	20	.500000	20	90	00
21	.001541	21	.539230	21	94	30
22	.006156	22	.578217	22	99	00
23	.013815	23	.616723	23	103	30
24	.024472	24	.654508	24	108	00
25	.038060	25	.691342	25	112	30
26	.054497	26	.726995	26	117	00
27	.073680	27	.761249	27	121	30
28	.095492	28	.793893	28	126	00
29	.119797	29	.824724	29	130	30
30	.146447	30	.853553	30	135	00
31	.175276	31	.880203	31	139	30
32	.206107	32	.904508	32	144	00
33	.238751	33	.926320	33	148	30
34	.273005	34	.945503	34	153	00
35	.308658	35	.961940	35	157	30
36	.345492	36	.975528	36	162	00
37	.383277	37	.986185	37	166	30
38	.421783	38	.993844	38	171	00
39	.460770	39	.998459	39	175	30
40	.500000	40	1.000000	40	180	00
41	.539230	41	.998459	41	184	30
42	.578217	42	.993844	42	189	00
43	.616723	43	.986185	43	193	30
44	.654508	44	.975528	44	198	00
45	.691342	45	.961940	45	202	30
46	.726995	46	.945503	46	207	00
47	.761249	47	.926320	47	211	30
48	.793893	48	.904508	48	216	00
49	.824724	49	.880203	49	220	30
50	.853553	50	.853553	50	225	00
51	.880203	51	.824724	51	229	30
52	.904508	52	.793893	52	234	00
53	.926320	53	.761249	53	238	30
54	.945503	54	.726995	54	243	00
55	.961940	55	.691342	55	247	30
56	.975528	56	.654508	56	252	00
57	.986185	57	.616723	57	256	30
58	.993844	58	.578217	58	261	00
59	.998459	59	.539230	59	265	30
60	1.000000	60	.500000	60	270	00
61	.998459	61	.460770	61	274	30
62	.993844	62	.421783	62	279	00
63	.986185	63	.383277	63	283	30
64	.975528	64	.345492	64	288	00
65	.961940	65	.308658	65	292	30
66	.945503	66	.273005	66	297	00
67	.926320	67	.238751	67	301	30
68	.904508	68	.206107	68	306	00
69	.880203	69	.175276	69	310	30
70	.853553	70	.146447	70	315	00
71	.824724	71	.119797	71	319	30
72	.793893	72	.095492	72	324	00
73	.761249	73	.073680	73	328	30
74	.726995	74	.054497	74	333	00
75	.691342	75	.038060	75	337	30
76	.654508	76	.024472	76	342	00
77	.616723	77	.013815	77	346	30
78	.578217	78	.006156	78	351	00
79	.539230	79	.001541	79	355	30
80	.500000	80	.000000	80	360	00

# 81 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

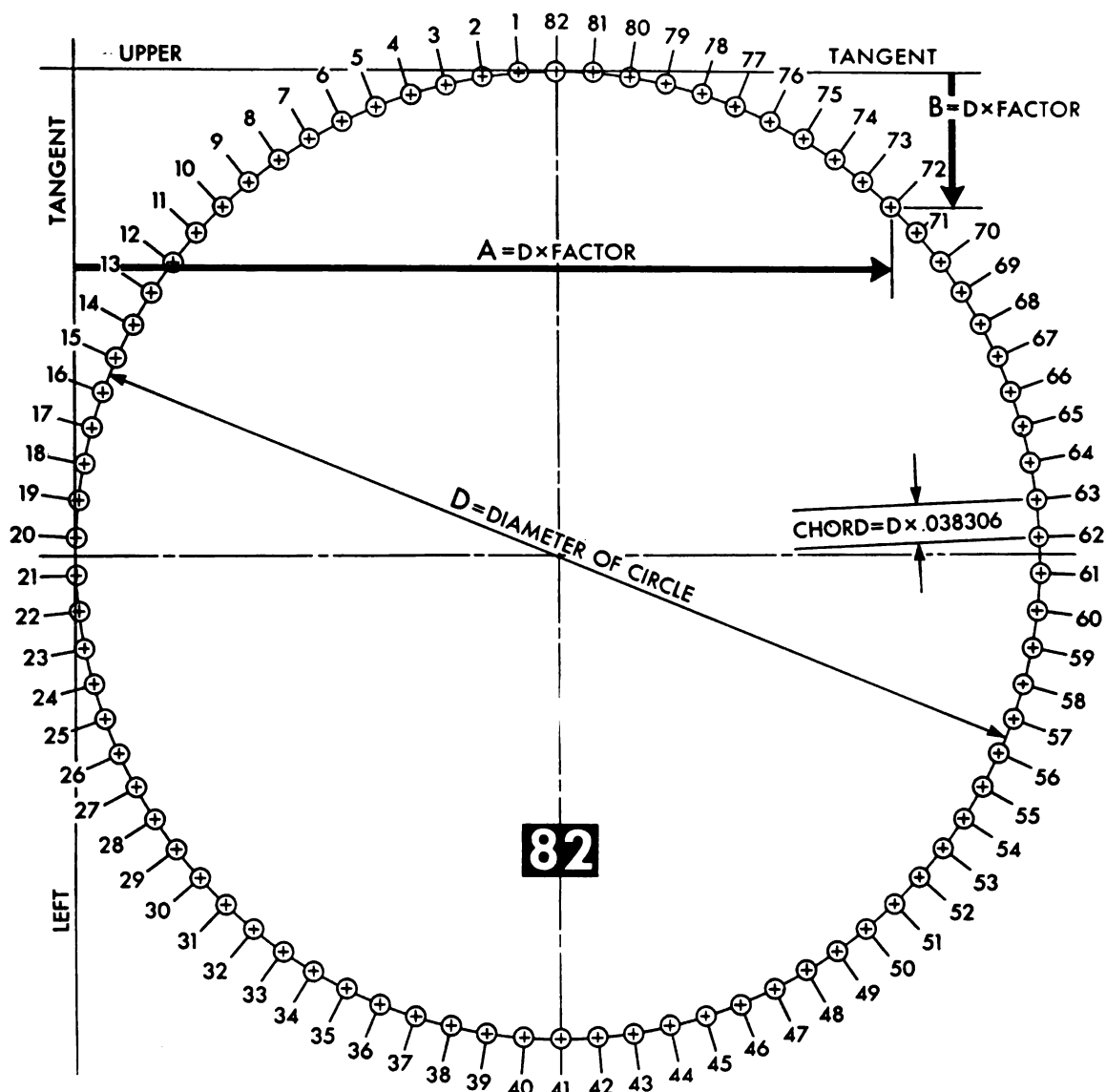


	FACTOR FOR "A"	FACTOR FOR "B"		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.461254	1	.001504	1	4	26
2	.422741	2	.006005	2	8	53
3	.384692	3	.013478	3	13	20
4	.347337	4	.023876	4	17	46
5	.310900	5	.037138	5	22	13
6	.275600	6	.053184	6	26	40
7	.241650	7	.071917	7	31	6
8	.209254	8	.093224	8	35	33
9	.178606	9	.116978	9	40	00
10	.149891	10	.143035	10	44	26
11	.123282	11	.171239	11	48	53
12	.098938	12	.201421	12	53	20
13	.077007	13	.233398	13	57	46
14	.057619	14	.266978	14	62	13
15	.040892	15	.301960	15	66	40
16	.026926	16	.338133	16	71	6
17	.015805	17	.375279	17	75	33

# COORDINATE FACTORS AND ANGLES—81 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
18		.007596	18	.413176	80	00	00
19		.002349	19	.451595	84	26	40
20		.000094	20	.490304	88	53	20
21		.000846	21	.529072	93	20	00
22		.004600	22	.567666	97	46	40
23		.011333	23	.605852	102	13	20
24		.021005	24	.643402	106	40	00
25		.033558	25	.680089	111	6	40
26		.048916	26	.715693	115	33	20
27		.066987	27	.750000	120	00	00
28		.087663	28	.782803	124	26	40
29		.110818	29	.813907	128	53	20
30		.136313	30	.843121	133	20	00
31		.163996	31	.870272	137	46	40
32		.193700	32	.895196	142	13	20
33		.225246	33	.917744	146	40	00
34		.258444	34	.937779	151	6	40
35		.293095	35	.955181	155	33	20
36		.328990	36	.969846	160	00	00
37		.365914	37	.981685	164	26	40
38		.403644	38	.990628	168	53	20
39		.441954	39	.996619	173	20	00
40		.480612	40	.999624	177	46	40
41		.519388	41	.999624	182	13	20
42		.558046	42	.996619	186	40	00
43		.596356	43	.990628	191	6	40
44		.634086	44	.981685	195	33	20
45		.671010	45	.969846	200	00	00
46		.706905	46	.955181	204	26	40
47		.741556	47	.937779	208	53	20
48		.774754	48	.917744	213	20	00
49		.806300	49	.895196	217	46	40
50		.836004	50	.870272	222	13	20
51		.863687	51	.843121	226	40	00
52		.889182	52	.813907	231	6	40
53		.912338	53	.782803	235	33	20
54		.933013	54	.750000	240	00	00
55		.951084	55	.715693	244	26	40
56		.966442	56	.680089	248	53	20
57		.978995	57	.643402	253	20	00
58		.988667	58	.605852	257	46	40
59		.995400	59	.567666	262	13	20
60		.999154	60	.529072	266	40	00
61		.999906	61	.490304	271	6	40
62		.997651	62	.451595	275	33	20
63		.992404	63	.413176	280	00	00
64		.984195	64	.375279	284	26	40
65		.973074	65	.338133	288	53	20
66		.959108	66	.301960	293	20	00
67		.942381	67	.266978	297	46	40
68		.922993	68	.233398	302	13	20
69		.901062	69	.201421	306	40	00
70		.876718	70	.171239	311	6	40
71		.850109	71	.143035	315	33	20
72		.821394	72	.116978	320	00	00
73		.790746	73	.093224	324	26	40
74		.758350	74	.071917	328	53	20
75		.724400	75	.053184	333	20	00
76		.689100	76	.037138	337	46	40
77		.652663	77	.023876	342	13	20
78		.615308	78	.013478	346	40	00
79		.577259	79	.006005	351	6	40
80		.538746	80	.001504	355	33	20
81		.500000	81	.000000	360	0	0

# 82 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

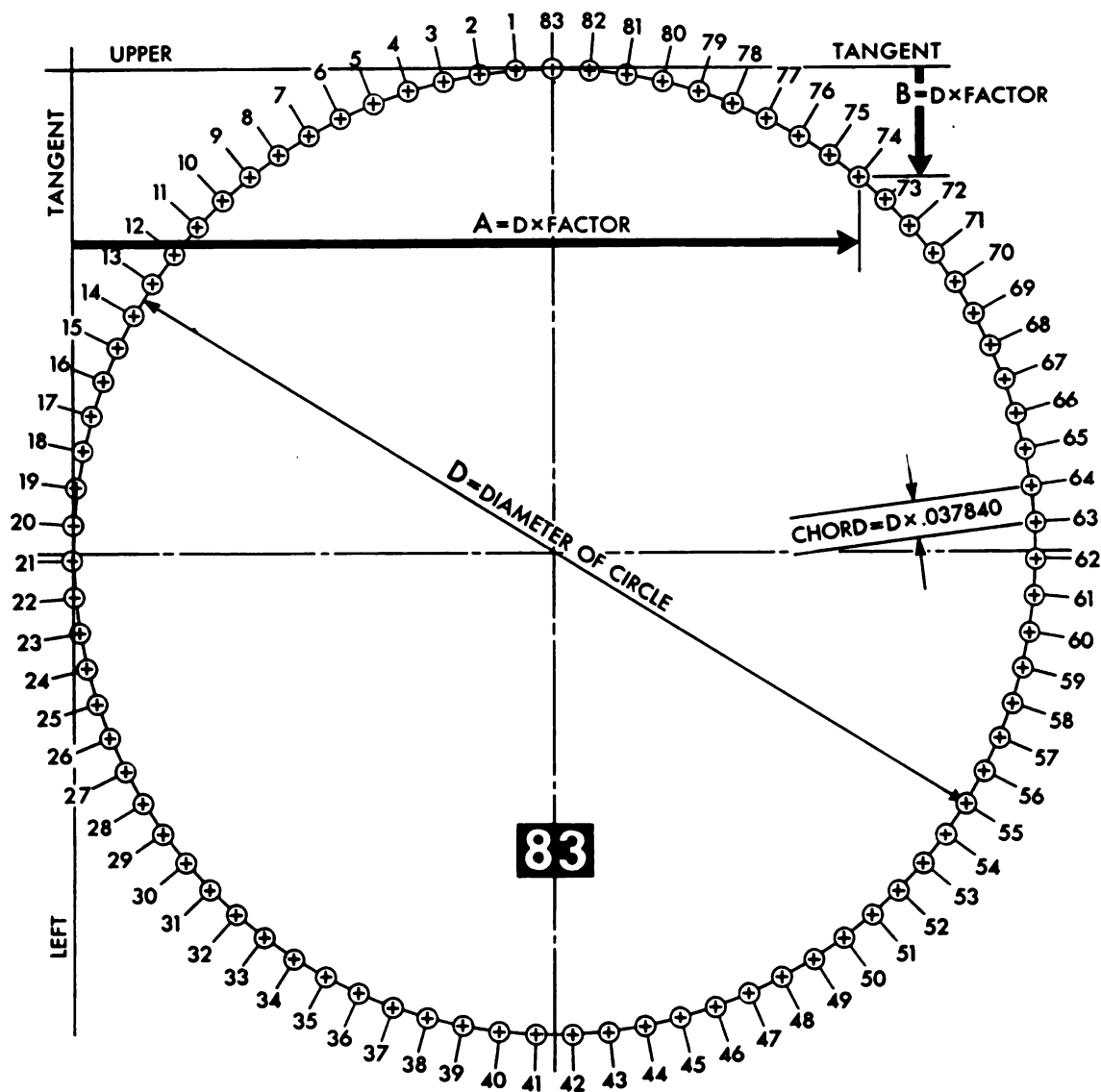


	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
1		.461725	1	.001467	1	4	23	24-72/82	
2		.423675	2	.005860	2	8	46	49-62/82	
3		.386073	3	.013152	3	13	10	14-52/82	
4		.349140	4	.023302	4	17	33	39-42/82	
5		.313091	5	.036249	5	21	57	4-32/82	
6		.278140	6	.051917	6	26	20	29-22/82	
7		.244491	7	.070215	7	30	43	54-12/82	
8		.212341	8	.091035	8	35	7	19- 2/82	
9		.181879	9	.114255	9	39	30	43-74/82	
10		.153284	10	.139739	10	43	54	8-64/82	
11		.126723	11	.167337	11	48	17	33-54/82	
12		.102354	12	.196887	12	52	40	58-44/82	
13		.080317	13	.228216	13	57	4	23-34/82	
14		.060744	14	.261140	14	61	27	48-24/82	
15		.043748	15	.295466	15	65	51	13-14/82	
16		.029430	16	.330992	16	70	14	38- 4/82	
17		.017873	17	.367509	17	74	38	2-76/82	

# COORDINATE FACTORS AND ANGLES—82 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
18		.009146	18	.404804	18	79	1
19		.003299	19	.442658	19	83	24
20		.000367	20	.480849	20	87	48
21		.000367	21	.519151	21	92	11
22		.003299	22	.557342	22	96	35
23		.009146	23	.595196	23	100	58
24		.017873	24	.632491	24	105	21
25		.029430	25	.669008	25	109	45
26		.043748	26	.704534	26	114	8
27		.060744	27	.738860	27	118	32
28		.080317	28	.771784	28	122	55
29		.102354	29	.803113	29	127	19
30		.126723	30	.832663	30	131	42
31		.153284	31	.860261	31	136	5
32		.181879	32	.885745	32	140	29
33		.212341	33	.908965	33	144	52
34		.244491	34	.929785	34	149	16
35		.278140	35	.948083	35	153	39
36		.313091	36	.963751	36	158	2
37		.349140	37	.976698	37	162	26
38		.386073	38	.986848	38	166	49
39		.423675	39	.994140	39	171	13
40		.461725	40	.998533	40	175	36
41		.500000	41	1.000000	41	180	00
42		.538275	42	.998533	42	184	23
43		.576325	43	.994140	43	188	46
44		.613927	44	.986848	44	193	10
45		.650860	45	.976698	45	197	33
46		.686909	46	.963751	46	201	57
47		.721860	47	.948083	47	206	20
48		.755509	48	.929785	48	210	43
49		.787659	49	.908965	49	215	7
50		.818121	50	.885745	50	219	30
51		.846716	51	.860261	51	223	54
52		.873277	52	.832663	52	228	17
53		.897646	53	.803113	53	232	40
54		.919683	54	.771784	54	237	4
55		.939256	55	.738860	55	241	27
56		.956252	56	.704534	56	245	51
57		.970570	57	.669008	57	250	14
58		.982127	58	.632491	58	254	38
59		.990854	59	.595196	59	259	1
60		.996701	60	.557342	60	263	24
61		.999633	61	.519151	61	267	48
62		.999633	62	.480849	62	272	11
63		.996701	63	.442658	63	276	35
64		.990854	64	.404804	64	280	58
65		.982127	65	.367509	65	285	21
66		.970570	66	.330992	66	289	45
67		.956252	67	.295466	67	294	8
68		.939256	68	.261140	68	298	32
69		.919683	69	.228216	69	302	55
70		.897646	70	.196887	70	307	19
71		.873277	71	.167337	71	311	42
72		.846716	72	.139739	72	316	5
73		.818121	73	.114255	73	320	29
74		.787659	74	.091035	74	324	52
75		.755509	75	.070215	75	329	16
76		.721860	76	.051917	76	333	39
77		.686909	77	.036249	77	338	2
78		.650860	78	.023302	78	342	26
79		.613927	79	.013152	79	346	49
80		.576325	80	.005859	80	351	13
81		.538275	81	.001467	81	355	36
82		.500000	82	.000000	82	360	0

# 83 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

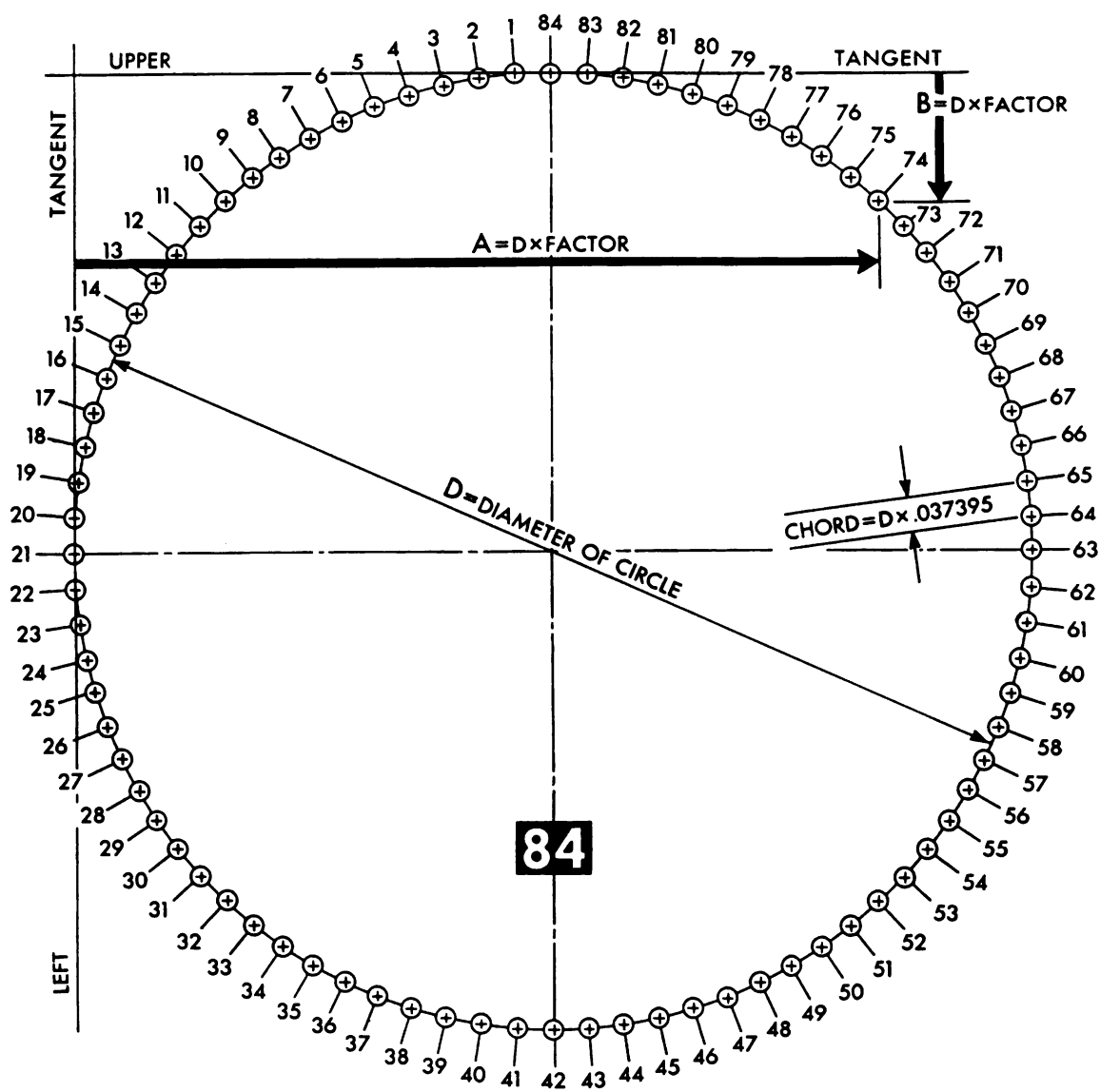


➡	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
1	.462186	1	.001432	1	4	20	14-38 /83
2	.424588	2	.005720	2	8	40	28-76 /83
3	.387422	3	.012838	3	13	00	43-31 /83
4	.350901	4	.022748	4	17	20	57-69 /83
5	.315234	5	.035391	5	21	41	12-24 /83
6	.280625	6	.050695	6	26	1	26-62 /83
7	.247273	7	.068573	7	30	21	41-17 /83
8	.215369	8	.088922	8	34	41	55-55 /83
9	.185095	9	.111626	9	39	2	10-10 /83
10	.156624	10	.136554	10	43	22	24-48 /83
11	.130121	11	.163564	11	47	42	39-3 /83
12	.105736	12	.192501	12	52	2	53-41 /83
13	.083609	13	.223199	13	56	23	7-79 /83
14	.063868	14	.255483	14	60	43	22-34 /83
15	.046624	15	.289167	15	65	3	36-72 /83
16	.031978	16	.324059	16	69	23	51-27 /83
17	.020012	17	.359959	17	73	44	5-65 /83

# COORDINATE FACTORS AND ANGLES—83 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
18		.010795		18	.396661	18	78	4	20-20/83
19		.004381		19	.433955	19	82	24	34-58/83
20		.000806		20	.471627	20	86	44	49-13/83
21		.000090		21	.509462	21	91	5	3-51/83
22		.002237		22	.547243	22	95	25	18- 6/83
23		.007235		23	.584752	23	99	45	32-44/83
24		.015056		24	.621777	24	104	5	46-82/83
25		.025655		25	.658104	25	108	26	1-37/83
26		.038971		26	.693525	26	112	46	15-75/83
27		.054927		27	.727838	27	117	6	30-30/83
28		.073433		28	.760846	28	121	26	44-68/83
29		.094382		29	.792359	29	125	46	59-23/83
30		.117654		30	.822199	30	130	7	13-61/83
31		.143117		31	.850192	31	134	27	28-16/83
32		.170624		32	.876180	32	138	47	42-54/83
33		.200017		33	.900013	33	143	7	57- 9/83
34		.231129		34	.921554	34	147	28	11-47/83
35		.263780		35	.940682	35	151	48	26- 2/83
36		.297785		36	.957284	36	156	8	40-40/83
37		.332948		37	.971268	37	160	28	54-78/83
38		.369068		38	.982552	38	164	49	9-33/83
39		.405938		39	.991073	39	169	9	23-71/83
40		.443346		40	.996780	40	173	29	38-26/83
41		.481079		41	.999642	41	177	49	52-64/83
42		.518921		42	.999642	42	182	10	7-19/83
43		.556654		43	.996780	43	186	30	21-57/83
44		.594062		44	.991073	44	190	50	36-12/83
45		.630932		45	.982552	45	195	10	50-50/83
46		.667052		46	.971268	46	199	31	5- 5/83
47		.702215		47	.957284	47	203	51	19-43/83
48		.736220		48	.940682	48	208	11	33-81/83
49		.768871		49	.921554	49	212	31	48-36/83
50		.799983		50	.900013	50	216	52	2-74/83
51		.829376		51	.876180	51	221	12	17-29/83
52		.856883		52	.850192	52	225	32	31-67/83
53		.882346		53	.822199	53	229	52	46-22/83
54		.905618		54	.792359	54	234	13	00-60/83
55		.926567		55	.760846	55	238	33	15-15/83
56		.945073		56	.727838	56	242	53	29-53/83
57		.961029		57	.693525	57	247	13	44- 8/83
58		.974345		58	.658104	58	251	33	58-46/83
59		.984944		59	.621777	59	255	54	13- 1/83
60		.992765		60	.584752	60	260	14	27-39/83
61		.997763		61	.547243	61	264	34	41-77/83
62		.999910		62	.509462	62	268	54	56-32/83
63		.999194		63	.471627	63	273	15	10-70/83
64		.995619		64	.433955	64	277	35	25-25/83
65		.989205		65	.396661	65	281	55	39-63/83
66		.979988		66	.359959	66	286	15	54-18/83
67		.968022		67	.324059	67	290	36	8-56/83
68		.953376		68	.289167	68	294	56	23-11/83
69		.936132		69	.255483	69	299	16	37-49/83
70		.916391		70	.223199	70	303	36	52- 4/83
71		.894264		71	.192501	71	307	57	6-42/83
72		.869879		72	.163564	72	312	17	20-80/83
73		.843376		73	.136554	73	316	37	35-35/83
74		.814905		74	.111626	74	320	57	49-73/83
75		.784631		75	.088922	75	325	18	4-28/83
76		.752727		76	.068573	76	329	38	18-66/83
77		.719375		77	.050695	77	333	58	33-21/83
78		.684766		78	.035391	78	338	18	47-59/83
79		.649099		79	.022748	79	342	39	2-14/83
80		.612578		80	.012838	80	346	59	16-52/83
81		.575412		81	.005720	81	351	19	31- 7/83
82		.537814		82	.001432	82	355	39	45-45/83
83		.500000		83	.000000	83	360	0	0

# 84 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

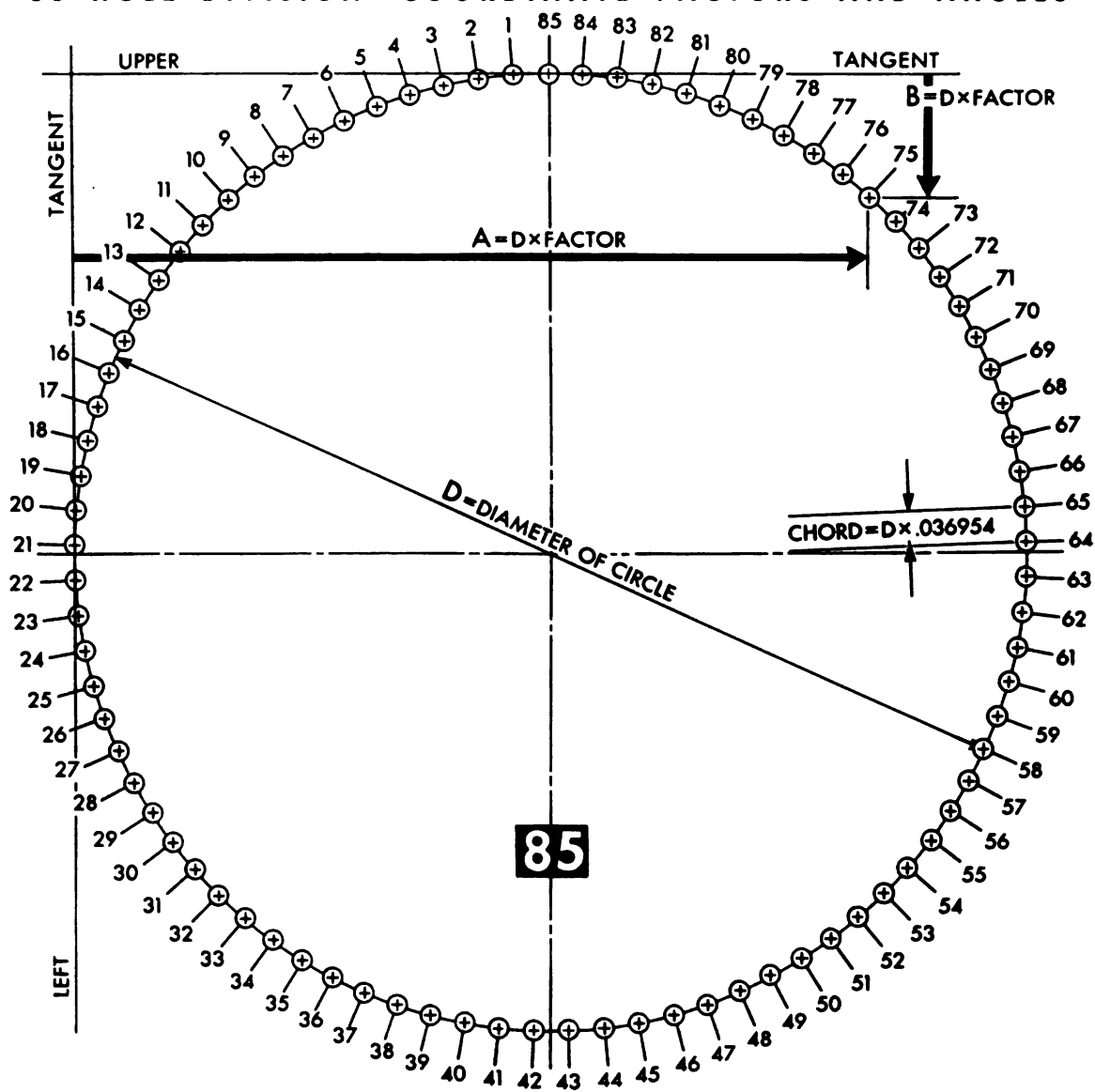


	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
1		.462635	1	.001398	1	4	17	8-48/84
2		.425479	2	.005585	2	8	34	17-12/84
3		.388740	3	.012536	3	12	51	25-60/84
4		.352622	4	.022214	4	17	8	34-24/84
5		.317329	5	.034563	5	21	25	42-72/84
6		.283058	6	.049516	6	25	42	51-36/84
7		.250000	7	.066987	7	30	00	00000000
8		.218340	8	.086881	8	34	17	8-48/84
9		.188255	9	.109084	9	38	34	17-12/84
10		.159914	10	.133474	10	42	51	25-60/84
11		.133474	11	.159914	11	47	8	34-24/84
12		.109084	12	.188255	12	51	25	42-72/84
13		.086881	13	.218340	13	55	42	51-36/84
14		.066987	14	.250000	14	60	00	00000000
15		.049516	15	.283058	15	64	17	8-48/84
16		.034563	16	.317329	16	68	34	17-12/84
17		.022214	17	.352622	17	72	51	25-60/84

# COORDINATE FACTORS AND ANGLES—84 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
18		.012536		18	.388740	18	77	8	34-24/84
19		.005585		19	.425479	19	81	25	42-72/84
20		.001398		20	.462635	20	85	42	51-36/84
21		.000000		21	.500000	21	90	00	00000000
22		.001398		22	.537365	22	94	17	8-48/84
23		.005584		23	.574521	23	98	34	17-12/84
24		.012536		24	.611260	24	102	51	25-60/84
25		.022214		25	.647378	25	107	8	34-24/84
26		.034563		26	.682671	26	111	25	42-72/84
27		.049516		27	.716942	27	115	42	51-36/84
28		.066987		28	.750000	28	120	00	00000000
29		.086881		29	.781660	29	124	17	8-48/84
30		.109084		30	.811745	30	128	34	17-12/84
31		.133474		31	.840086	31	132	51	25-60/84
32		.159914		32	.866526	32	137	8	34-24/84
33		.188255		33	.890916	33	141	25	42-72/84
34		.218340		34	.913119	34	145	42	51-36/84
35		.250000		35	.933013	35	150	00	00000000
36		.283058		36	.950484	36	154	17	8-48/84
37		.317329		37	.965437	37	158	34	17-12/84
38		.352622		38	.977786	38	162	51	25-60/84
39		.388740		39	.987464	39	167	8	34-24/84
40		.425479		40	.994415	40	171	25	42-72/84
41		.462635		41	.998602	41	175	42	51-36/84
42		.500000		42	1.000000	42	180	00	00000000
43		.537365		43	.998602	43	184	17	8-48/84
44		.574521		44	.994415	44	188	34	17-12/84
45		.611260		45	.987464	45	192	51	25-60/84
46		.647378		46	.977786	46	197	8	34-24/84
47		.682671		47	.965437	47	201	25	42-72/84
48		.716942		48	.950484	48	205	42	51-36/84
49		.750000		49	.933013	49	210	00	00000000
50		.781660		50	.913119	50	214	17	8-48/84
51		.811745		51	.890916	51	218	34	17-12/84
52		.840086		52	.866526	52	222	51	25-60/84
53		.866526		53	.840086	53	227	8	34-24/84
54		.890916		54	.811745	54	231	25	42-72/84
55		.913119		55	.781660	55	235	42	51-36/84
56		.933013		56	.750000	56	240	00	00000000
57		.950484		57	.716942	57	244	17	8-48/84
58		.965437		58	.682671	58	248	34	17-12/84
59		.977786		59	.647378	59	252	51	25-60/84
60		.987464		60	.611260	60	257	8	34-24/84
61		.994415		61	.574521	61	261	25	42-72/84
62		.998602		62	.537365	62	265	42	51-36/84
63		1.000000		63	.500000	63	270	00	00000000
64		.998602		64	.462635	64	274	17	8-48/84
65		.994415		65	.425479	65	278	34	17-12/84
66		.987464		66	.388740	66	282	51	25-60/84
67		.977786		67	.352622	67	287	8	34-24/84
68		.965437		68	.317329	68	291	25	42-72/84
69		.950484		69	.283058	69	295	42	51-36/84
70		.933013		70	.250000	70	300	00	00000000
71		.913119		71	.218340	71	304	17	8-48/84
72		.890916		72	.188255	72	308	34	17-12/84
73		.866526		73	.159914	73	312	51	25-60/84
74		.840086		74	.133474	74	317	8	34-24/84
75		.811745		75	.109084	75	321	25	42-72/84
76		.781660		76	.086881	76	325	42	51-36/84
77		.750000		77	.066987	77	330	00	00000000
78		.716942		78	.049516	78	334	17	8-48/84
79		.682671		79	.034563	79	338	34	17-12/84
80		.647378		80	.022214	80	342	51	25-60/84
81		.611260		81	.012536	81	347	8	34-24/84
82		.574521		82	.005585	82	351	25	42-72/84
83		.537365		83	.001398	83	355	42	51-36/84
84		.500000		84	.000000	84	360	0	0

# 85 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.463074	1	.001365	1	4	14 7-5/85
2		.426349	2	.005454	2	8	28 14-10/85
3		.390027	3	.012244	3	12	42 21-15/85
4		.354305	4	.021697	4	16	56 28-20/85
5		.319379	5	.033764	5	21	10 35-25/85
6		.285440	6	.048376	6	25	24 42-30/85
7		.252672	7	.065456	7	29	38 49-35/85
8		.221255	8	.084908	8	33	52 56-40/85
9		.191361	9	.106628	9	38	7 3-45/85
10		.163152	10	.130496	10	42	21 10-50/85
11		.136783	11	.156382	11	46	35 17-55/85
12		.112398	12	.184145	12	50	49 24-60/85
13		.090130	13	.213632	13	55	3 31-65/85
14		.070100	14	.244684	14	59	17 38-70/85
15		.052418	15	.277131	15	63	31 45-75/85
16		.037181	16	.310794	16	67	45 52-80/85
17		.024472	17	.345492	17	72	00 00000000

# COORDINATE FACTORS AND ANGLES—85 HOLE DIVISION

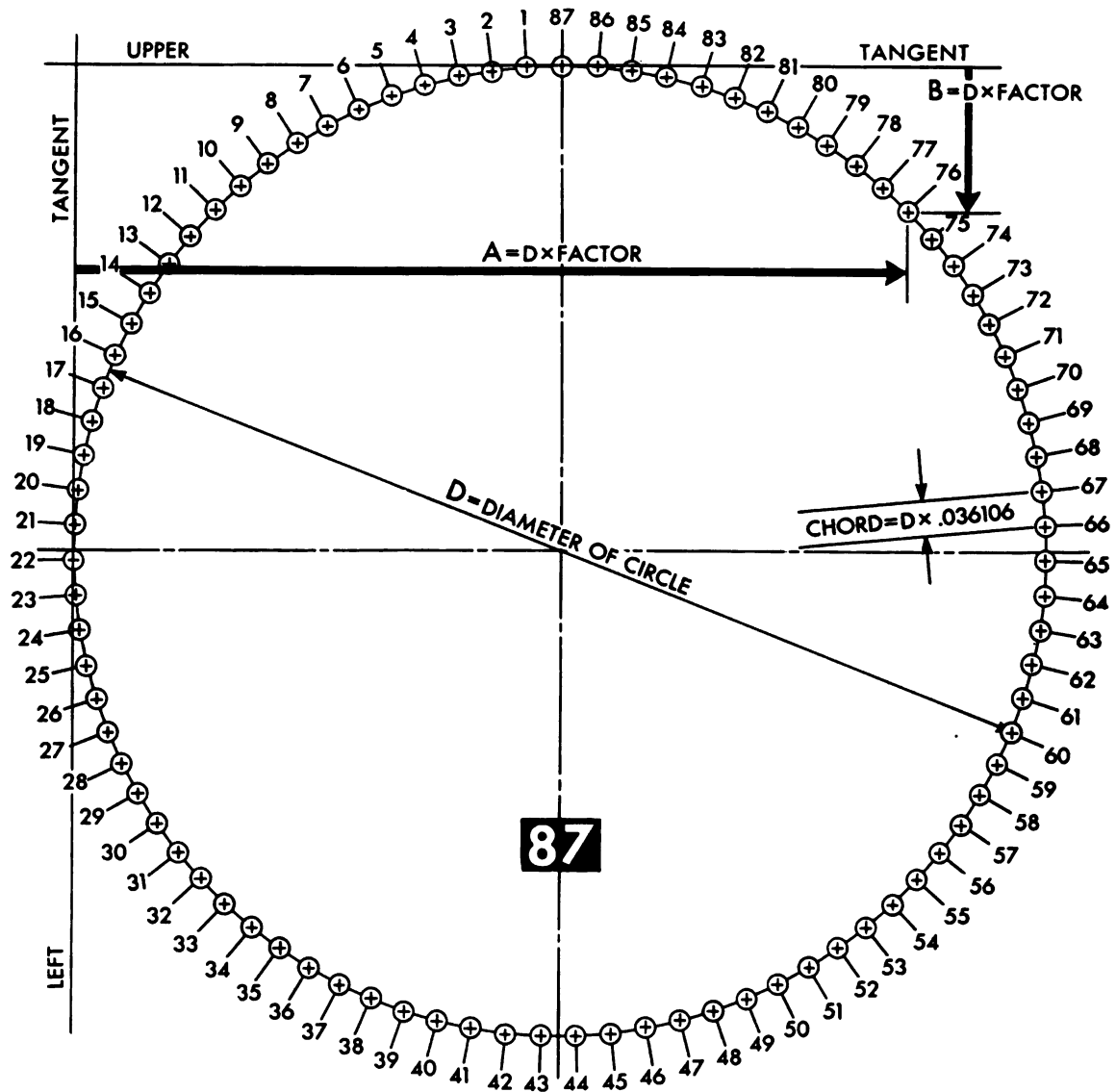
	→ FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
18	.014359	18	.381032	18	76	14	7-	5/85
19	.006900	19	.417223	19	80	28	14-	10/85
20	.002133	20	.453866	20	84	42	21-	15/85
21	.000085	21	.490760	21	88	56	28-	20/85
22	.000768	22	.527705	22	93	10	35-	25/85
23	.004178	23	.564500	23	97	24	42-	30/85
24	.010295	24	.600941	24	101	38	49-	35/85
25	.019087	25	.636832	25	105	52	56-	40/85
26	.030506	26	.671974	26	110	7	3-	45/85
27	.044489	27	.706178	27	114	21	10-	50/85
28	.060959	28	.739256	28	118	35	17-	55/85
29	.079828	29	.771027	29	122	49	24-	60/85
30	.100991	30	.801317	30	127	3	31-	65/85
31	.124334	31	.829962	31	131	17	38-	70/85
32	.149728	32	.856805	32	135	31	45-	75/85
33	.177036	33	.881699	33	139	45	52-	80/85
34	.206107	34	.904508	34	144	00	00000000	
35	.236784	35	.925109	35	148	14	7-	5/85
36	.268898	36	.943387	36	152	28	14-	10/85
37	.302274	37	.959243	37	156	42	21-	15/85
38	.336731	38	.972592	38	160	56	28-	20/85
39	.372079	39	.983359	39	165	10	35-	25/85
40	.408125	40	.991487	40	169	24	42-	30/85
41	.444672	41	.996930	41	173	38	49-	35/85
42	.481524	42	.999659	42	177	52	56-	40/85
43	.518476	43	.999659	43	182	7	3-	45/85
44	.555328	44	.996930	44	186	21	10-	50/85
45	.591875	45	.991487	45	190	35	17-	55/85
46	.627921	46	.983359	46	194	49	24-	60/85
47	.663269	47	.972592	47	199	3	31-	65/85
48	.697726	48	.959243	48	203	17	38-	70/85
49	.731102	49	.943387	49	207	31	45-	75/85
50	.763216	50	.925109	50	211	45	52-	80/85
51	.793893	51	.904508	51	216	00	00000000	
52	.822964	52	.881699	52	220	14	7-	5/85
53	.850272	53	.856805	53	224	28	14-	10/85
54	.875666	54	.829962	54	228	42	21-	15/85
55	.899009	55	.801317	55	232	56	28-	20/85
56	.920172	56	.771027	56	237	10	35-	25/85
57	.939041	57	.739256	57	241	24	42-	30/85
58	.955511	58	.706178	58	245	38	49-	35/85
59	.969494	59	.671974	59	249	52	56-	40/85
60	.980913	60	.636832	60	254	7	3-	45/85
61	.989705	61	.600941	61	258	21	10-	50/85
62	.995822	62	.564500	62	262	35	17-	55/85
63	.999232	63	.527705	63	266	49	24-	60/85
64	.999915	64	.490760	64	271	3	31-	65/85
65	.997867	65	.453866	65	275	17	38-	70/85
66	.993100	66	.417223	66	279	31	45-	75/85
67	.985641	67	.381032	67	283	45	52-	80/85
68	.975528	68	.345492	68	288	00	00000000	
69	.962819	69	.310794	69	292	14	7-	5/85
70	.947582	70	.277131	70	296	28	14-	10/85
71	.929900	71	.244684	71	300	42	21-	15/85
72	.909870	72	.213632	72	304	56	28-	20/85
73	.887602	73	.184145	73	309	10	35-	25/85
74	.863217	74	.156382	74	313	24	42-	30/85
75	.836848	75	.130496	75	317	38	49-	35/85
76	.808639	76	.106628	76	321	52	56-	40/85
77	.778745	77	.084908	77	326	7	3-	45/85
78	.747328	78	.065456	78	330	21	10-	50/85
79	.714560	79	.048376	79	334	35	17-	55/85
80	.680621	80	.033764	80	338	49	24-	60/85
81	.645695	81	.021697	81	343	3	31-	65/85
82	.609973	82	.012244	82	347	17	38-	70/85
83	.573651	83	.005454	83	351	31	45-	75/85
84	.536926	84	.001365	84	355	45	52-	80/85
85	.500000	85	.000000	85	360	0	0	0

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# COORDINATE FACTORS AND ANGLES—86 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
18		.016258		18	.373533	18	75	20	55-70/86
19		.008317		19	.409182	19	79	32	5-50/86
20		.003000		20	.445314	20	83	43	15-30/86
21		.000334		21	.481739	21	87	54	25-10/86
22		.000334		22	.518261	22	92	5	34-76/86
23		.003000		23	.554686	23	96	16	44-56/86
24		.008317		24	.590818	24	100	27	54-36/86
25		.016258		25	.626467	25	104	39	4-16/86
26		.026780		26	.661440	26	108	50	13-82/86
27		.039827		27	.695552	27	113	1	23-62/86
28		.055329		28	.728621	28	117	12	33-42/86
29		.073203		29	.760470	29	121	23	43-22/86
30		.093355		30	.790929	30	125	34	53- 2/86
31		.115676		31	.819837	31	129	46	2-68/86
32		.140048		32	.847037	32	133	57	12-48/86
33		.166342		33	.872386	33	138	8	22-28/86
34		.194413		34	.895748	34	142	19	32- 8/86
35		.224116		35	.916999	35	146	30	41-74/86
36		.255291		36	.936025	36	150	41	51-54/86
37		.287772		37	.952724	37	154	53	1-34/86
38		.321384		38	.967008	38	159	4	11-14/86
39		.355950		39	.978800	39	163	15	20-80/86
40		.391285		40	.988038	40	167	26	30-60/86
41		.427199		41	.994672	41	171	37	40-40/86
42		.463502		42	.998666	42	175	48	50-20/86
43		.500000		43	1.000000	43	180	00	00000000
44		.536498		44	.998666	44	184	11	9-66/86
45		.572801		45	.994672	45	188	22	19-46/86
46		.608715		46	.988038	46	192	33	29-26/86
47		.644050		47	.978800	47	196	44	39- 6/86
48		.678616		48	.967008	48	200	55	48-72/86
49		.712228		49	.952724	49	205	6	58-52/86
50		.744709		50	.936025	50	209	18	8-32/86
51		.775884		51	.916999	51	213	29	18-12/86
52		.805587		52	.895748	52	217	40	27-78/86
53		.833658		53	.872386	53	221	51	37-58/86
54		.859952		54	.847037	54	226	2	47-38/86
55		.884324		55	.819837	55	230	13	57-18/86
56		.906645		56	.790929	56	234	25	6-84/86
57		.926797		57	.760470	57	238	36	16-64/86
58		.944671		58	.728621	58	242	47	26-44/86
59		.960173		59	.695552	59	246	58	36-24/86
60		.973220		60	.661440	60	251	9	46- 4/86
61		.983742		61	.626467	61	255	20	55-70/86
62		.991683		62	.590818	62	259	32	5-50/86
63		.997000		63	.554686	63	263	43	15-30/86
64		.999666		64	.518261	64	267	54	25-10/86
65		.999666		65	.481739	65	272	5	34-76/86
66		.997000		66	.445314	66	276	16	44-56/86
67		.991683		67	.409182	67	280	27	54-36/86
68		.983742		68	.373533	68	284	39	4-16/86
69		.973220		69	.338560	69	288	50	13-82/86
70		.960173		70	.304448	70	293	1	23-62/86
71		.944671		71	.271379	71	297	12	33-42/86
72		.926797		72	.239530	72	301	23	43-22/86
73		.906645		73	.209071	73	305	34	53- 2/86
74		.884324		74	.180163	74	309	46	2-68/86
75		.859952		75	.152963	75	313	57	12-48/86
76		.833658		76	.127614	76	318	8	22-28/86
77		.805587		77	.104252	77	322	19	32- 8/86
78		.775884		78	.083001	78	326	30	41-74/86
79		.744709		79	.063975	79	330	41	51-54/86
80		.712228		80	.047276	80	334	53	1-34/86
81		.678616		81	.032992	81	339	4	11-14/86
82		.644050		82	.021200	82	343	15	20-80/86
83		.608715		83	.011962	83	347	26	30-60/86
84		.572801		84	.005328	84	351	37	40-40/86
85		.536498		85	.001334	85	355	48	50-20/86
86		.500000		86	.000000	86	360	0	0

# 87 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

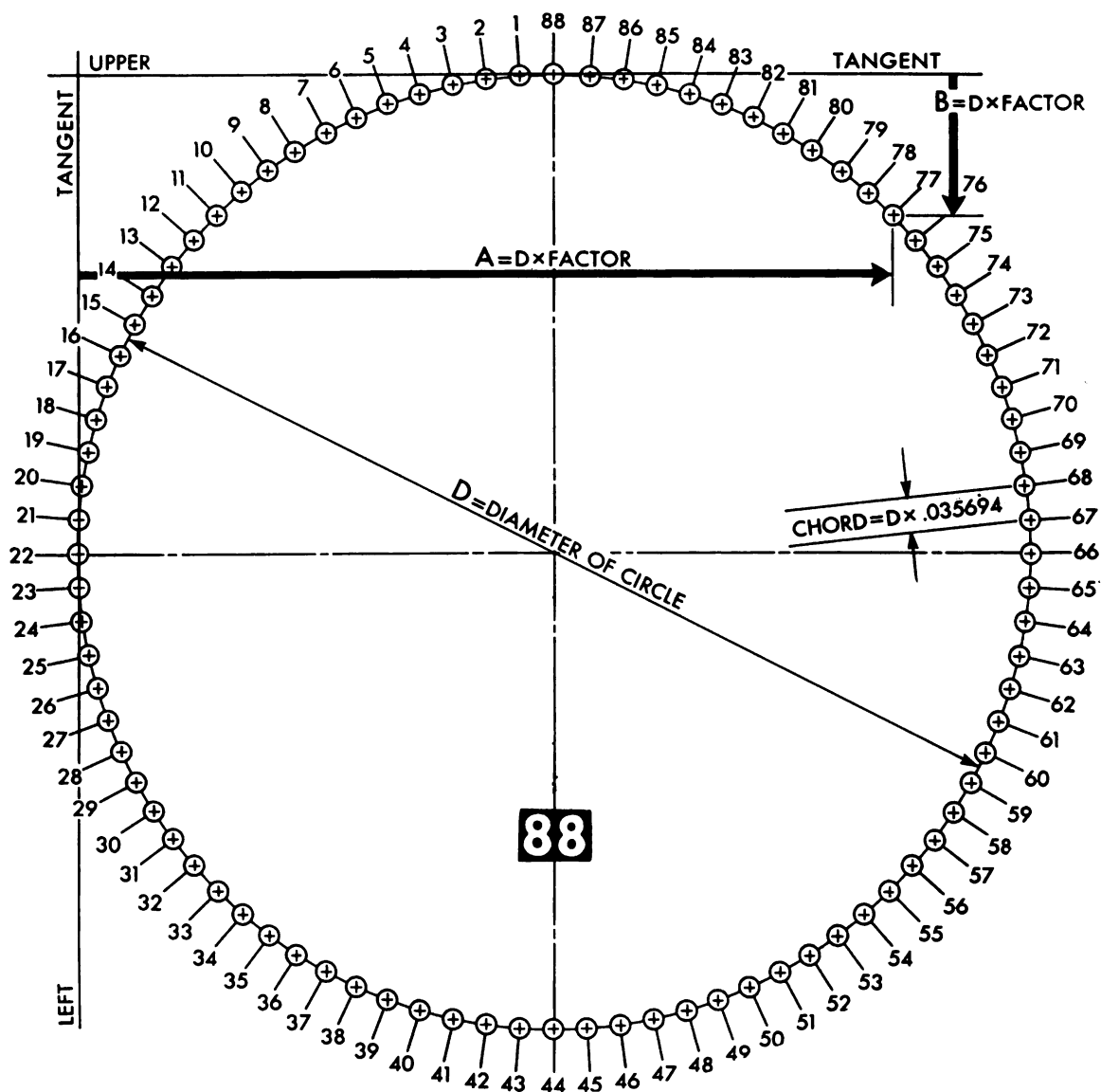


	➔	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
1		.463921	1		.001303	1	4	8
2		.428030	2		.005207	2	8	16
3		.392515	3		.011690	3	12	24
4		.357560	4		.020719	4	16	33
5		.323347	5		.032246	5	20	41
6		.290055	6		.046212	6	24	49
7		.257859	7		.062544	7	28	57
8		.226924	8		.081157	8	33	6
9		.197413	9		.101953	9	37	14
10		.169480	10		.124825	10	41	22
11		.143269	11		.149652	11	45	31
12		.118919	12		.176307	12	49	39
13		.096555	13		.204649	13	53	47
14		.076295	14		.234530	14	57	55
15		.058244	15		.265796	15	62	4
16		.042496	16		.298283	16	66	12
17		.029133	17		.331821	17	70	20

# COORDINATE FACTORS AND ANGLES—87 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
18	.018225	18	.366236	18	74	28	57-81/87
19	.009829	19	.401348	19	78	37	14-42/87
20	.003988	20	.436975	20	82	45	31- 3/87
21	.000733	21	.472931	21	86	53	47-51/87
22	.000082	22	.509027	22	91	2	4-12/87
23	.002036	23	.545077	23	95	10	20-60/87
24	.006587	24	.580891	24	99	18	37-21/87
25	.013710	25	.616284	25	103	26	53-69/87
26	.023368	26	.651071	26	107	35	10-30/87
27	.035512	27	.685069	27	111	43	26-78/87
28	.050077	28	.718103	28	115	51	43-39/87
29	.066987	29	.750000	29	120	00	00000000
30	.086156	30	.780594	30	124	8	16-48/87
31	.107481	31	.809724	31	128	16	33- 9/87
32	.130853	32	.837240	32	132	24	49-57/87
33	.156150	33	.862998	33	136	33	6-18/87
34	.183240	34	.886863	34	140	41	22-66/87
35	.211981	35	.908711	35	144	49	39-27/87
36	.242223	36	.928429	36	148	57	55-75/87
37	.273809	37	.945912	37	153	6	12-36/87
38	.306575	38	.961071	38	157	14	28-84/87
39	.340349	39	.973827	39	161	22	45-45/87
40	.374956	40	.984111	40	165	31	2- 6/87
41	.410214	41	.991872	41	169	39	18-54/87
42	.445941	42	.997069	42	173	47	35-15/87
43	.481949	43	.999674	43	177	55	51-63/87
44	.518051	44	.999674	44	182	4	8-24/87
45	.554060	45	.997069	45	186	12	24-72/87
46	.589786	46	.991872	46	190	20	41-33/87
47	.625044	47	.984111	47	194	28	57-81/87
48	.659651	48	.973827	48	198	37	14-42/87
49	.693425	49	.961071	49	202	45	31- 3/87
50	.726191	50	.945912	50	206	53	47-51/87
51	.757777	51	.928429	51	211	2	4-12/87
52	.788019	52	.908711	52	215	10	20-60/87
53	.816760	53	.886863	53	219	18	37-21/87
54	.843850	54	.862998	54	223	26	53-69/87
55	.869147	55	.837240	55	227	35	10-30/87
56	.892519	56	.809724	56	231	43	26-78/87
57	.913844	57	.780594	57	235	51	43-39/87
58	.933013	58	.750000	58	240	00	00000000
59	.949923	59	.718103	59	244	8	16-48/87
60	.964488	60	.685069	60	248	16	33- 9/87
61	.976632	61	.651071	61	252	24	49-57/87
62	.986290	62	.616284	62	256	33	6-18/87
63	.993413	63	.580891	63	260	41	22-66/87
64	.997964	64	.545077	64	264	49	39-27/87
65	.999919	65	.509027	65	268	57	55-75/87
66	.999267	66	.472931	66	273	6	12-36/87
67	.996012	67	.436975	67	277	14	28-84/87
68	.990171	68	.401348	68	281	22	45-45/87
69	.981775	69	.366236	69	285	31	2- 6/87
70	.970867	70	.331821	70	289	39	18-54/87
71	.957504	71	.298283	71	293	47	35-15/87
72	.941756	72	.265796	72	297	55	51-63/87
73	.923705	73	.234530	73	302	4	8-24/87
74	.903445	74	.204649	74	306	12	24-72/87
75	.881081	75	.176307	75	310	20	41-33/87
76	.856731	76	.149652	76	314	28	57-81/87
77	.830520	77	.124825	77	318	37	14-42/87
78	.802587	78	.101953	78	322	45	31- 3/87
79	.773076	79	.081157	79	326	53	47-51/87
80	.742142	80	.062544	80	331	2	4-12/87
81	.709945	81	.046212	81	335	10	20-60/87
82	.676653	82	.032246	82	339	18	37-21/87
83	.642440	83	.020719	83	343	26	53-69/87
84	.607485	84	.011690	84	347	35	10-30/87
85	.571970	85	.005207	85	351	43	26-78/87
86	.536079	86	.001303	86	355	51	43-39/87
87	.500000	87	.000000	87	360	0	0

# 88 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

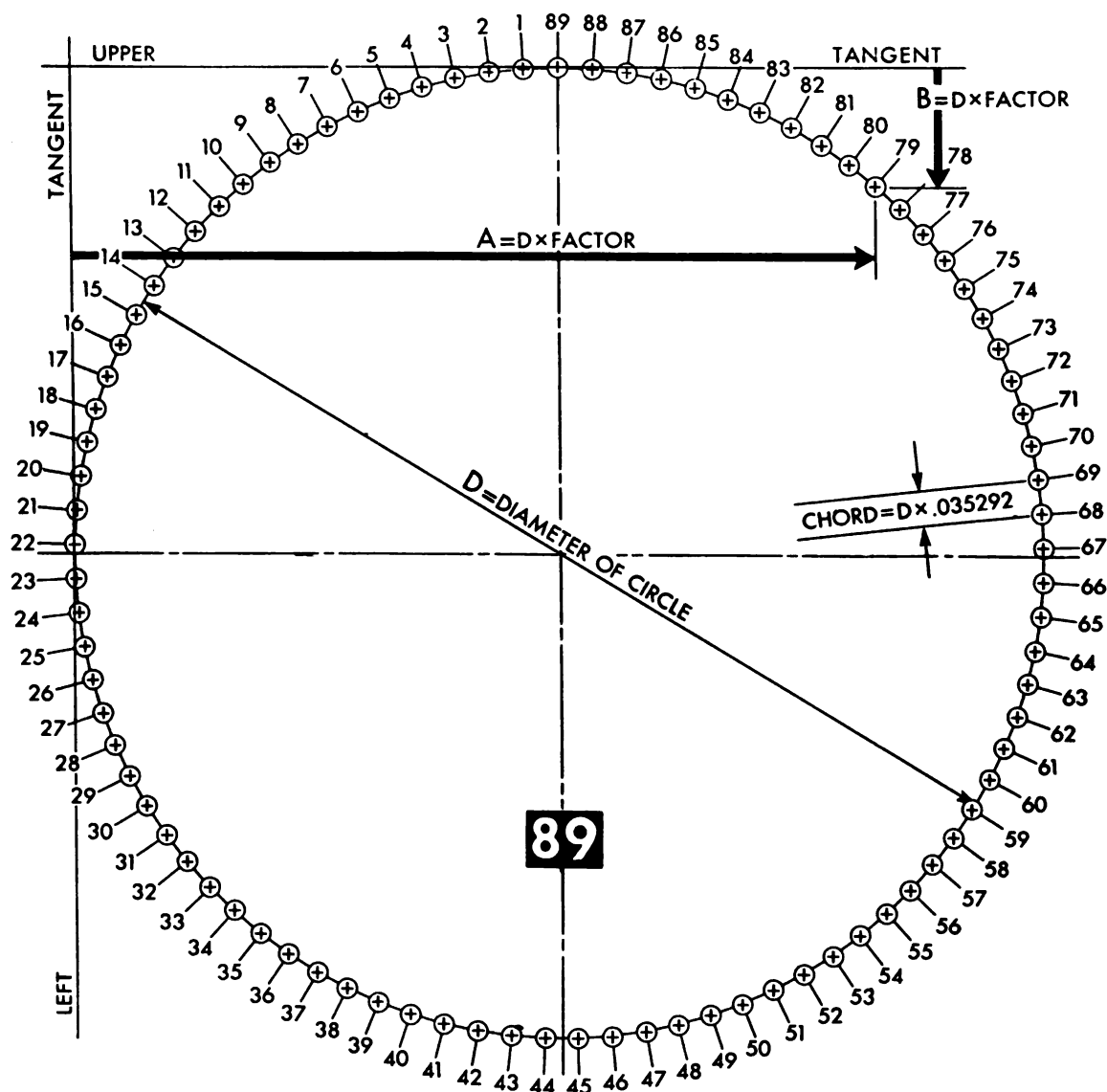


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.464330	1	.001274	1	4	5	27-24 /88
2	.428843	2	.005089	2	8	10	54-48 /88
3	.393717	3	.011427	3	12	16	21-72 /88
4	.359134	4	.020254	4	16	21	49- 8 /88
5	.325268	5	.031525	5	20	27	16-32 /88
6	.292293	6	.045184	6	24	32	43-56 /88
7	.260376	7	.061161	7	28	38	10-80 /88
8	.229680	8	.079373	8	32	43	38-16 /88
9	.200361	9	.099729	9	36	49	5-40 /88
10	.172570	10	.122125	10	40	54	32-64 /88
11	.146447	11	.146447	11	45	00	00000000
12	.122125	12	.172570	12	49	5	27-24 /88
13	.099729	13	.200361	13	53	10	54-48 /88
14	.079373	14	.229680	14	57	16	21-72 /88
15	.061161	15	.260376	15	61	21	49- 8 /88
16	.045184	16	.292293	16	65	27	16-32 /88
17	.031525	17	.325268	17	69	32	43-56 /88
18	.020254	18	.359134	18	73	38	10-80 /88

# COORDINATE FACTORS AND ANGLES—88 HOLE DIVISION

➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
19	.011427	19	.393717	19	77	43	38-16/88
20	.005089	20	.428843	20	81	49	5-40/88
21	.001274	21	.464330	21	85	54	32-64/88
22	.000000	22	.500000	22	90	00	00000000
23	.001274	23	.535670	23	94	5	27-24/88
24	.005089	24	.571157	24	98	10	54-48/88
25	.011427	25	.606283	25	102	16	21-72/88
26	.020254	26	.640866	26	106	21	49- 8/88
27	.031525	27	.674732	27	110	27	16-32/88
28	.045184	28	.707708	28	114	32	43-56/88
29	.061161	29	.739624	29	118	38	10-80/88
30	.079373	30	.770320	30	122	43	38-16/88
31	.099729	31	.799639	31	126	49	5-40/88
32	.122125	32	.827430	32	130	54	32-64/88
33	.146447	33	.853553	33	135	00	00000000
34	.172570	34	.877875	34	139	5	27-24/88
35	.200361	35	.900271	35	143	10	54-48/88
36	.229680	36	.920627	36	147	16	21-72/88
37	.260376	37	.938839	37	151	21	49- 8/88
38	.292293	38	.954816	38	155	27	16-32/88
39	.325268	39	.968475	39	159	32	43-56/88
40	.359134	40	.979746	40	163	38	10-80/88
41	.393717	41	.988573	41	167	43	38-16/88
42	.428843	42	.994911	42	171	49	5-40/88
43	.464330	43	.998726	43	175	54	32-64/88
44	.500000	44	1.000000	44	180	00	00000000
45	.535670	45	.998726	45	184	5	27-24/88
46	.571157	46	.994911	46	188	10	54-48/88
47	.606283	47	.988573	47	192	16	21-72/88
48	.640866	48	.979746	48	196	21	49- 8/88
49	.674732	49	.968475	49	200	27	16-32/88
50	.707708	50	.954816	50	204	32	43-56/88
51	.739624	51	.938839	51	208	38	10-80/88
52	.770320	52	.920627	52	212	43	38-16/88
53	.799639	53	.900271	53	216	49	5-40/88
54	.827430	54	.877875	54	220	54	32-64/88
55	.853553	55	.853553	55	225	00	00000000
56	.877875	56	.827430	56	229	5	27-24/88
57	.900271	57	.799639	57	233	10	54-48/88
58	.920627	58	.770320	58	237	16	21-72/88
59	.938839	59	.739624	59	241	21	49- 8/88
60	.954816	60	.707708	60	245	27	16-32/88
61	.968475	61	.674732	61	249	32	43-56/88
62	.979746	62	.640866	62	253	38	10-80/88
63	.988573	63	.606283	63	257	43	38-16/88
64	.994911	64	.571157	64	261	49	5-40/88
65	.998726	65	.535670	65	265	54	32-64/88
66	1.000000	66	.500000	66	270	00	00000000
67	.998726	67	.464330	67	274	5	27-24/88
68	.994911	68	.428843	68	278	10	54-48/88
69	.988573	69	.393717	69	282	16	21-72/88
70	.979746	70	.359134	70	286	21	49- 8/88
71	.968475	71	.325268	71	290	27	16-32/88
72	.954816	72	.292293	72	294	32	43-56/88
73	.938839	73	.260376	73	298	38	10-80/88
74	.920627	74	.229680	74	302	43	38-16/88
75	.900271	75	.200361	75	306	49	5-40/88
76	.877875	76	.172570	76	310	54	32-64/88
77	.853553	77	.146447	77	315	00	00000000
78	.827430	78	.122125	78	319	5	27-24/88
79	.799639	79	.099729	79	323	10	54-48/88
80	.770320	80	.079373	80	327	16	21-72/88
81	.739624	81	.061161	81	331	21	49- 8/88
82	.707708	82	.045184	82	335	27	16-32/88
83	.674732	83	.031525	83	339	32	43-56/88
84	.640866	84	.020254	84	343	38	10-80/88
85	.606283	85	.011427	85	347	43	38-16/88
86	.571157	86	.005089	86	351	49	5-40/88
87	.535670	87	.001274	87	355	54	32-64/88
88	.500000	88	.000000	88	360	0	0

# 89 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.464731	1	.001245	1	4	2	41-71/89
2	.429637	2	.004976	2	8	5	23-53/89
3	.394894	3	.011172	3	12	8	5-35/89
4	.360674	4	.019804	4	16	10	47-17/89
5	.327148	5	.030828	5	20	13	28-88/89
6	.294484	6	.044190	6	24	16	10-70/89
7	.262844	7	.059822	7	28	18	52-52/89
8	.232385	8	.077647	8	32	21	34-34/89
9	.203259	9	.097576	9	36	24	16-16/89
10	.175612	10	.119511	10	40	26	57-87/89
11	.149580	11	.143340	11	44	29	39-69/89
12	.125295	12	.168947	12	48	32	21-51/89
13	.102876	13	.196203	13	52	35	3-33/89
14	.082436	14	.224972	14	56	37	45-15/89
15	.064076	15	.255112	15	60	40	26-86/89
16	.047888	16	.286472	16	64	43	8-68/89
17	.033952	17	.318896	17	68	45	50-50/89
18	.022338	18	.352221	18	72	48	32-32/89

# COORDINATE FACTORS AND ANGLES—89 HOLE DIVISION

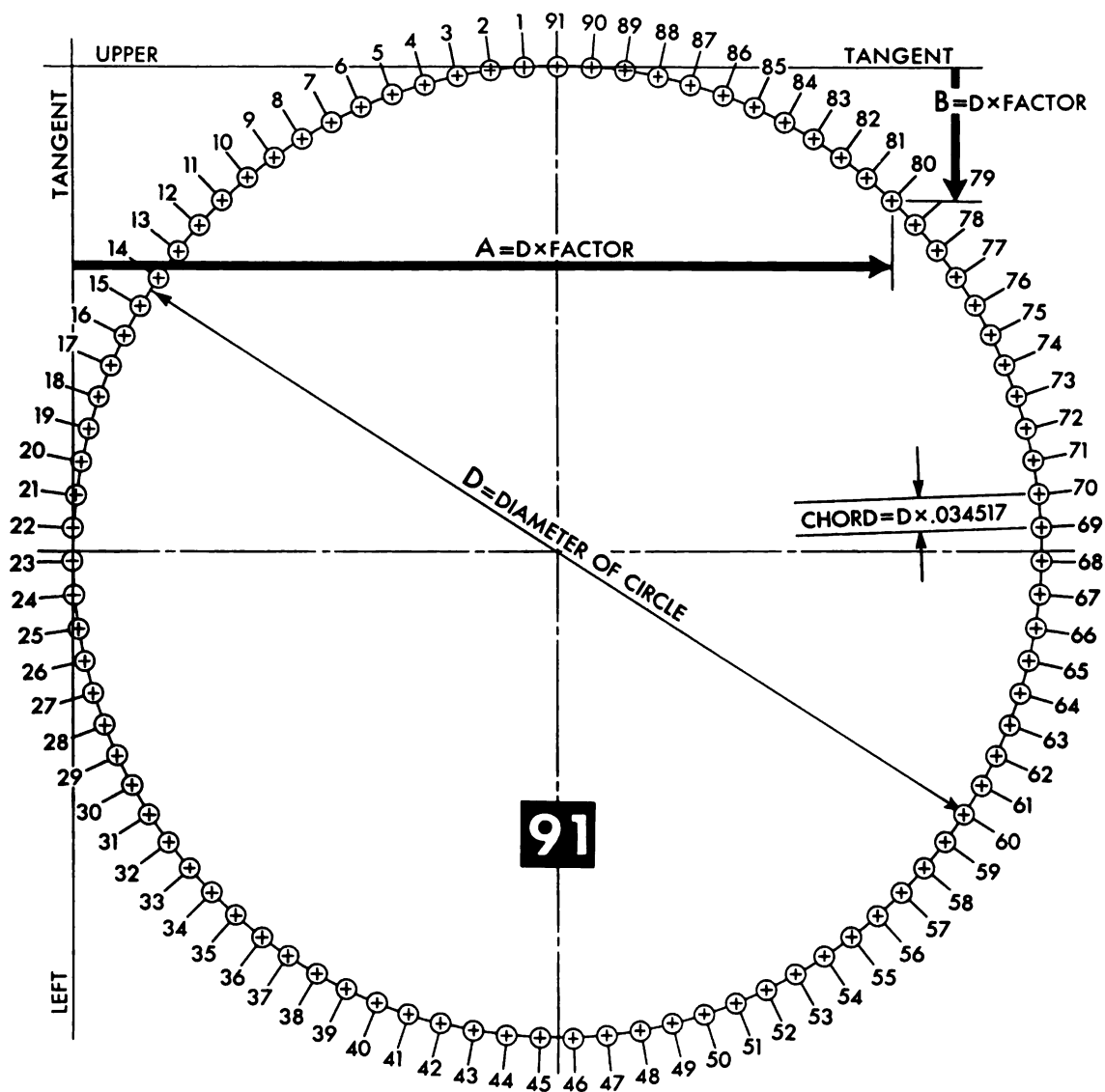
	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
19		.013103	19	.386283	19	76	51	14-14/89
20		.006295	20	.420911	20	80	53	55-85/89
21		.001946	21	.455934	21	84	56	37-67/89
22		.000078	22	.491176	22	88	59	19-49/89
23		.000701	23	.526462	23	93	2	1-31/89
24		.003811	24	.561616	24	97	4	43-13/89
25		.009393	25	.596463	25	101	7	24-84/89
26		.017420	26	.630830	26	105	10	6-66/89
27		.027851	27	.664544	27	109	12	48-48/89
28		.040633	28	.697439	28	113	15	30-30/89
29		.055705	29	.729351	29	117	18	12-12/89
30		.072990	30	.760120	30	121	20	53-83/89
31		.092402	31	.789593	31	125	23	35-65/89
32		.113845	32	.817623	32	129	26	17-47/89
33		.137212	33	.844071	33	133	28	59-29/89
34		.162386	34	.868804	34	137	31	41-11/89
35		.189243	35	.891701	35	141	34	22-82/89
36		.217646	36	.912645	36	145	37	4-64/89
37		.247457	37	.931534	37	149	39	46-46/89
38		.278526	38	.948274	38	153	42	28-28/89
39		.310698	39	.962780	39	157	45	10-10/89
40		.343814	40	.974980	40	161	47	51-81/89
41		.377708	41	.984814	41	165	50	33-63/89
42		.412210	42	.992233	42	169	53	15-45/89
43		.447151	43	.997199	43	173	55	57-27/89
44		.482354	44	.999689	44	177	58	39- 9/89
45		.517646	45	.999689	45	182	1	20-80/89
46		.552849	46	.997199	46	186	4	2-62/89
47		.587790	47	.992233	47	190	6	44-44/89
48		.622292	48	.984814	48	194	9	26-26/89
49		.656186	49	.974980	49	198	12	8- 8/89
50		.689302	50	.962780	50	202	14	49-79/89
51		.721474	51	.948274	51	206	17	31-61/89
52		.752543	52	.931534	52	210	20	13-43/89
53		.782354	53	.912645	53	214	22	55-25/89
54		.810757	54	.891701	54	218	25	37- 7/89
55		.837614	55	.868804	55	222	28	18-78/89
56		.862788	56	.844071	56	226	31	00-60/89
57		.886155	57	.817623	57	230	33	42-42/89
58		.907598	58	.789593	58	234	36	24-24/89
59		.927010	59	.760120	59	238	39	6- 6/89
60		.944295	60	.729351	60	242	41	47-77/89
61		.959367	61	.697439	61	246	44	29-59/89
62		.972149	62	.664544	62	250	47	11-41/89
63		.982580	63	.630830	63	254	49	53-23/89
64		.990607	64	.596463	64	258	52	35- 5/89
65		.996189	65	.561616	65	262	55	16-76/89
66		.999299	66	.526462	66	266	57	58-58/89
67		.999922	67	.491176	67	271	00	40-40/89
68		.998054	68	.455934	68	275	3	22-22/89
69		.993705	69	.420911	69	279	6	4- 4/89
70		.986897	70	.386283	70	283	8	45-75/89
71		.977662	71	.352221	71	287	11	27-57/89
72		.966048	72	.318896	72	291	14	9-39/89
73		.952112	73	.286472	73	295	16	51-21/89
74		.935924	74	.255112	74	299	19	33- 3/89
75		.917564	75	.224972	75	303	22	14-74/89
76		.897124	76	.196203	76	307	24	56-56/89
77		.874705	77	.168947	77	311	27	38-38/89
78		.850420	78	.143340	78	315	30	20-20/89
79		.824388	79	.119511	79	319	33	2- 2/89
80		.796741	80	.097576	80	323	35	43-73/89
81		.767615	81	.077647	81	327	38	25-55/89
82		.737156	82	.059822	82	331	41	7-37/89
83		.705516	83	.044190	83	335	43	49-19/89
84		.672852	84	.030828	84	339	46	31- 1/89
85		.639326	85	.019804	85	343	49	12-72/89
86		.605106	86	.011172	86	347	51	54-54/89
87		.570363	87	.004976	87	351	54	36-36/89
88		.535269	88	.001245	88	355	57	18-18/89
89		.500000	89	.000000	89	360	0	0

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# COORDINATE FACTORS AND ANGLES—90 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
19		.014852	19	.379039	19	76	0	0
20		.007596	20	.413176	20	80	0	0
21		.002739	21	.447736	21	84	0	0
22		.000305	22	.482550	22	88	0	0
23		.000305	23	.517450	23	92	0	0
24		.002739	24	.552264	24	96	0	0
25		.007596	25	.586824	25	100	0	0
26		.014852	26	.620961	26	104	0	0
27		.024472	27	.654508	27	108	0	0
28		.036408	28	.687303	28	112	0	0
29		.050603	29	.719186	29	116	0	0
30		.066987	30	.750000	30	120	0	0
31		.085481	31	.779596	31	124	0	0
32		.105995	32	.807831	32	128	0	0
33		.128428	33	.834565	33	132	0	0
34		.152671	34	.859670	34	136	0	0
35		.178606	35	.883022	35	140	0	0
36		.206107	36	.904508	36	144	0	0
37		.235040	37	.924024	37	148	0	0
38		.265264	38	.941474	38	152	0	0
39		.296632	39	.956773	39	156	0	0
40		.328990	40	.969846	40	160	0	0
41		.362181	41	.980631	41	164	0	0
42		.396044	42	.989074	42	168	0	0
43		.430413	43	.995134	43	172	0	0
44		.465122	44	.998782	44	176	0	0
45		.500000	45	1.000000	45	180	0	0
46		.534878	46	.998782	46	184	0	0
47		.569587	47	.995134	47	188	0	0
48		.603956	48	.989074	48	192	0	0
49		.637819	49	.980631	49	196	0	0
50		.671010	50	.969846	50	200	0	0
51		.703368	51	.956773	51	204	0	0
52		.734736	52	.941474	52	208	0	0
53		.764960	53	.924024	53	212	0	0
54		.793893	54	.904508	54	216	0	0
55		.821394	55	.883022	55	220	0	0
56		.847329	56	.859670	56	224	0	0
57		.871572	57	.834565	57	228	0	0
58		.894005	58	.807831	58	232	0	0
59		.914519	59	.779596	59	236	0	0
60		.933013	60	.750000	60	240	0	0
61		.949397	61	.719186	61	244	0	0
62		.963592	62	.687303	62	248	0	0
63		.975528	63	.654508	63	252	0	0
64		.985148	64	.620961	64	256	0	0
65		.992404	65	.586824	65	260	0	0
66		.997261	66	.552264	66	264	0	0
67		.999695	67	.517450	67	268	0	0
68		.999695	68	.482550	68	272	0	0
69		.997261	69	.447736	69	276	0	0
70		.992404	70	.413176	70	280	0	0
71		.985148	71	.379039	71	284	0	0
72		.975528	72	.345492	72	288	0	0
73		.963592	73	.312697	73	292	0	0
74		.949397	74	.280814	74	296	0	0
75		.933013	75	.250000	75	300	0	0
76		.914519	76	.220404	76	304	0	0
77		.894005	77	.192169	77	308	0	0
78		.871572	78	.165435	78	312	0	0
79		.847329	79	.140330	79	316	0	0
80		.821394	80	.116978	80	320	0	0
81		.793893	81	.095492	81	324	0	0
82		.764960	82	.075976	82	328	0	0
83		.734736	83	.058526	83	332	0	0
84		.703368	84	.043227	84	336	0	0
85		.671010	85	.030154	85	340	0	0
86		.637819	86	.019369	86	344	0	0
87		.603956	87	.010926	87	348	0	0
88		.569587	88	.004866	88	352	0	0
89		.534878	89	.001218	89	356	0	0
90		.500000	90	.000000	90	360	0	0

# 91 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

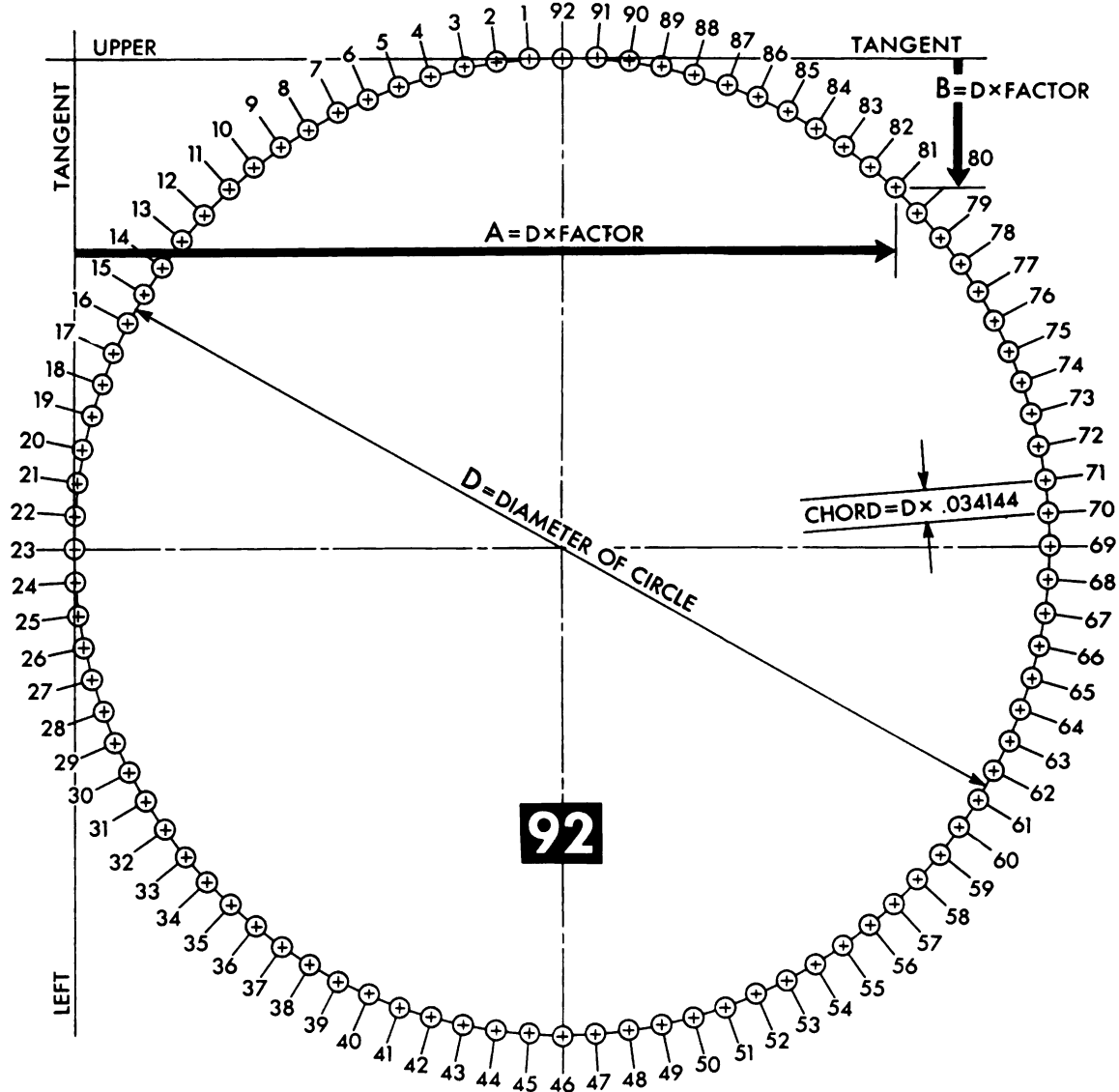


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.465504	1	.001192	3	57	21-69/91
2	.431173	2	.004759	7	54	43-47/91
3	.397171	3	.010688	11	52	5-25/91
4	.363657	4	.018948	15	49	27-3/91
5	.330793	5	.029501	19	46	48-72/91
6	.298737	6	.042296	23	44	10-50/91
7	.267638	7	.057272	27	41	32-28/91
8	.237648	8	.074358	31	38	54-6/91
9	.208907	9	.093472	35	36	15-75/91
10	.181554	10	.114523	39	33	37-53/91
11	.155718	11	.137412	43	30	59-31/91
12	.131523	12	.162028	47	28	21-9/91
13	.109084	13	.188255	51	25	42-78/91
14	.088508	14	.215968	55	23	4-56/91
15	.069893	15	.245034	59	20	26-34/91
16	.053327	16	.275315	63	17	48-12/91
17	.038890	17	.306667	67	15	9-81/91
18	.026651	18	.338940	71	12	31-59/91

# COORDINATE FACTORS AND ANGLES—91 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
19		.016667		19	.371980	75	9	53-37/91
20		.008986		20	.405631	79	7	15-15/91
21		.003646		21	.439732	83	4	36-84/91
22		.000670		22	.474119	87	1	58-62/91
23		.000074		23	.508630	90	59	20-40/91
24		.001861		24	.543100	94	56	42-18/91
25		.006022		25	.577365	98	54	3-87/91
26		.012536		26	.611260	102	51	25-65/91
27		.021374		27	.644626	106	48	47-43/91
28		.032492		28	.677302	110	46	9-21/91
29		.045838		29	.709134	114	43	30-90/91
30		.061349		30	.739969	118	40	52-68/91
31		.078950		31	.769660	122	38	14-46/91
32		.098557		32	.798066	126	35	36-24/91
33		.120077		33	.825052	130	32	58- 2/91
34		.143408		34	.850489	134	30	19-71/91
35		.168439		35	.874255	138	27	41-49/91
36		.195049		36	.896238	142	25	3-27/91
37		.223113		37	.916333	146	22	25- 5/91
38		.252496		38	.934444	150	19	46-74/91
39		.283058		39	.950484	154	17	8-52/91
40		.314655		40	.964378	158	14	30-30/91
41		.347134		41	.976059	162	11	52- 8/91
42		.380342		42	.985471	166	9	13-77/91
43		.414120		43	.992569	170	6	35-55/91
44		.448308		44	.997321	174	3	57-33/91
45		.482742		45	.999702	178	1	19-11/91
46		.517258		46	.999702	181	58	40-80/91
47		.551692		47	.997321	185	56	2-58/91
48		.585880		48	.992569	189	53	24-36/91
49		.619658		49	.985471	193	50	46-14/91
50		.652866		50	.976059	197	48	7-83/91
51		.685346		51	.964378	201	45	29-61/91
52		.716942		52	.950484	205	42	51-39/91
53		.747504		53	.934444	209	40	13-17/91
54		.776887		54	.916333	213	37	34-86/91
55		.804951		55	.896238	217	34	56-64/91
56		.831561		56	.874255	221	32	18-42/91
57		.856592		57	.850489	225	29	40-20/91
58		.879923		58	.825052	229	27	1-89/91
59		.901443		59	.798066	233	24	23-67/91
60		.921050		60	.769660	237	21	45-45/91
61		.938651		61	.739969	241	19	7-23/91
62		.954162		62	.709134	245	16	29- 1/91
63		.967508		63	.677302	249	13	50-70/91
64		.978626		64	.644626	253	11	12-48/91
65		.987464		65	.611260	257	8	34-26/91
66		.993978		66	.577365	261	5	56- 4/91
67		.998139		67	.543100	265	3	17-73/91
68		.999926		68	.508630	269	00	39-51/91
69		.999330		69	.474119	272	58	1-29/91
70		.996354		70	.439732	276	55	23- 7/91
71		.991014		71	.405631	280	52	44-76/91
72		.983333		72	.371980	284	50	6-54/91
73		.973349		73	.338940	288	47	28-32/91
74		.961110		74	.306667	292	44	50-10/91
75		.946673		75	.275315	296	42	11-79/91
76		.930107		76	.245034	300	39	33-57/91
77		.911492		77	.215968	304	36	55-35/91
78		.890916		78	.188255	308	34	17-13/91
79		.868477		79	.162028	312	31	38-82/91
80		.844282		80	.137412	316	29	00-60/91
81		.818446		81	.114523	320	26	22-38/91
82		.791093		82	.093472	324	23	44-16/91
83		.762352		83	.074358	328	21	5-85/91
84		.732362		84	.057272	332	18	27-63/91
85		.701263		85	.042296	336	15	49-41/91
86		.669207		86	.029501	340	13	11-19/91
87		.636343		87	.018948	344	10	32-88/91
88		.602829		88	.010688	348	7	54-66/91
89		.568827		89	.004759	352	5	16-44/91
90		.534496		90	.001192	356	2	38-22/91
91		.500000		91	.000000	360	0	0

# 92 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

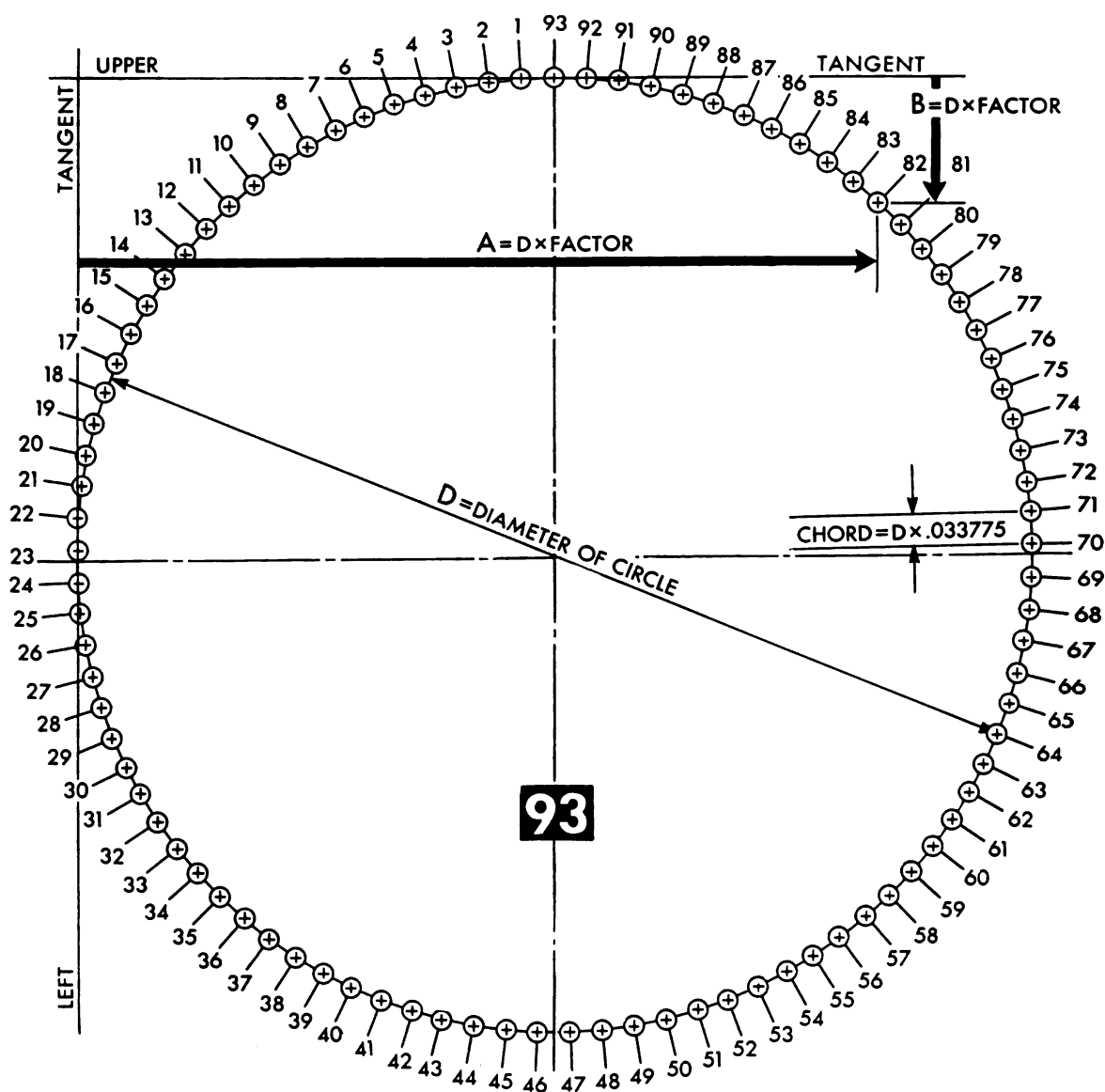


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.465879	1	.001166	1	3	46-88/92
2		.431917	2	.004657	2	7	33-84/92
3		.398272	3	.010458	3	11	20-80/92
4		.365102	4	.018541	4	15	7-76/92
5		.332560	5	.028870	5	19	54-72/92
6		.300803	6	.041394	6	23	41-68/92
7		.269967	7	.056057	7	27	28-64/92
8		.240208	8	.072790	8	31	15-60/92
9		.211660	9	.091515	9	35	2-56/92
10		.184456	10	.112144	10	39	49-52/92
11		.158723	11	.134582	11	43	36-48/92
12		.134582	12	.158723	12	46	23-44/92
13		.112144	13	.184456	13	50	10-40/92
14		.091515	14	.211660	14	54	57-36/92
15		.072790	15	.240208	15	58	44-32/92
16		.056057	16	.269967	16	62	31-28/92
17		.041394	17	.300803	17	66	18-24/92
18		.028870	18	.332560	18	70	5-20/92
19		.018541	19	.365102	19	74	52-16/92

# COORDINATE FACTORS AND ANGLES—92 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
20	.010458	20	.398272	78	15	39-12/92
21	.004657	21	.431917	82	10	26- 8/92
22	.001166	22	.465879	86	5	13- 4/92
23	.000000	23	.500000	90	00	00000000
24	.001166	24	.534121	93	54	46-88/92
25	.004657	25	.568083	97	49	33-84/92
26	.010458	26	.601728	101	44	20-80/92
27	.018541	27	.634898	105	39	7-76/92
28	.028870	28	.667440	109	33	54-72/92
29	.041394	29	.699197	113	28	41-68/92
30	.056057	30	.730033	117	23	28-64/92
31	.072790	31	.759792	121	18	15-60/92
32	.091515	32	.788340	125	13	2-56/92
33	.112144	33	.815544	129	7	49-52/92
34	.134582	34	.841277	133	2	36-48/92
35	.158723	35	.865418	136	57	23-44/92
36	.184456	36	.887856	140	52	10-40/92
37	.211660	37	.908485	144	46	57-36/92
38	.240208	38	.927210	148	41	44-32/92
39	.269967	39	.943943	152	36	31-28/92
40	.300803	40	.958606	156	31	18-24/92
41	.332560	41	.971130	160	26	5-20/92
42	.365102	42	.981459	164	20	52-16/92
43	.398272	43	.989542	168	15	39-12/92
44	.431917	44	.995343	172	10	26- 8/92
45	.465879	45	.998834	176	5	13- 4/92
46	.500000	46	1.000000	180	00	00000000
47	.534121	47	.998834	183	54	46-88/92
48	.568083	48	.995343	187	49	33-84/92
49	.601728	49	.989542	191	44	20-80/92
50	.634898	50	.981459	195	39	7-76/92
51	.667440	51	.971130	199	33	54-72/92
52	.699197	52	.958606	203	28	41-68/92
53	.730033	53	.943943	207	23	28-64/92
54	.759792	54	.927210	211	18	15-60/92
55	.788340	55	.908485	215	13	2-56/92
56	.815544	56	.887856	219	7	49-52/92
57	.841277	57	.865418	223	2	36-48/92
58	.865418	58	.841277	226	57	23-44/92
59	.887856	59	.815544	230	52	10-40/92
60	.908485	60	.788340	234	46	57-36/92
61	.927210	61	.759792	238	41	44-32/92
62	.943943	62	.730033	242	36	31-28/92
63	.958606	63	.699197	246	31	18-24/92
64	.971130	64	.667440	250	26	5-20/92
65	.981459	65	.634898	254	20	52-16/92
66	.989542	66	.601728	258	15	39-12/92
67	.995343	67	.568083	262	10	26- 8/92
68	.998834	68	.534121	266	5	13- 4/92
69	1.000000	69	.500000	270	00	00000000
70	.998834	70	.465879	273	54	46-88/92
71	.995343	71	.431917	277	49	33-84/92
72	.989542	72	.398272	281	44	20-80/92
73	.981459	73	.365102	285	39	7-76/92
74	.971130	74	.332560	289	33	54-72/92
75	.958606	75	.300803	293	28	41-68/92
76	.943943	76	.269967	297	23	28-64/92
77	.927210	77	.240208	301	18	15-60/92
78	.908485	78	.211660	305	13	2-56/92
79	.887856	79	.184456	309	7	49-52/92
80	.865418	80	.158723	313	2	36-48/92
81	.841277	81	.134582	316	57	23-44/92
82	.815544	82	.112144	320	52	10-40/92
83	.788340	83	.091515	324	46	57-36/92
84	.759792	84	.072790	328	41	44-32/92
85	.730033	85	.056057	332	36	31-28/92
86	.699197	86	.041394	336	31	18-24/92
87	.667440	87	.028870	340	26	5-20/92
88	.634898	88	.018541	344	20	52-16/92
89	.601728	89	.010458	348	15	39-12/92
90	.568083	90	.004657	352	10	26- 8/92
91	.534121	91	.001166	356	5	13- 4/92
92	.500000	92	.000000	360	0	0

# 93 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

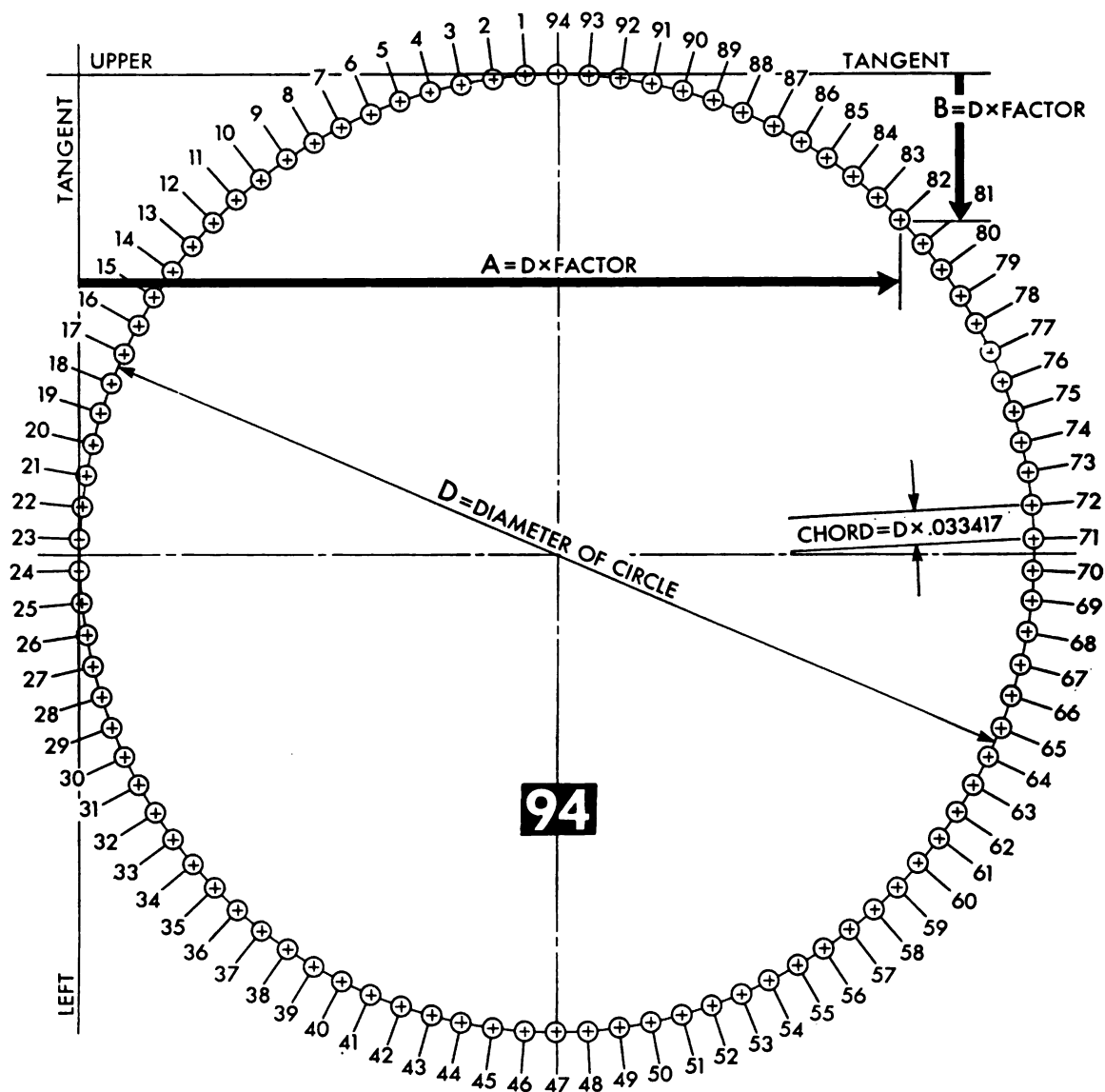


	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.466245	1	.001141	3	52	15-45/93
2	.432644	2	.004558	7	44	30-90/93
3	.399351	3	.010235	11	36	46-42/93
4	.366516	4	.018147	15	29	1-87/93
5	.334291	5	.028258	19	21	17-39/93
6	.302822	6	.040521	23	13	32-84/93
7	.272253	7	.054881	27	5	48-36/93
8	.242722	8	.071271	30	58	3-81/93
9	.214366	9	.089618	34	50	19-33/93
10	.187313	10	.109838	38	42	34-78/93
11	.161686	11	.131837	42	34	50-30/93
12	.137604	12	.155517	46	27	5-75/93
13	.115174	13	.180768	50	19	21-27/93
14	.094501	14	.207476	54	11	36-72/93
15	.075678	15	.235518	58	3	52-24/93
16	.058791	16	.264767	61	56	7-69/93
17	.043917	17	.295090	65	48	23-21/93
18	.031124	18	.326347	69	40	38-66/93
19	.020470	19	.358397	73	32	54-18/93

# COORDINATE FACTORS AND ANGLES—93 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
20		.012005		20	.391093	20	77	25	9-63/93
21		.005766		21	.424286	21	81	17	25-15/93
22		.001782		22	.457824	22	85	9	40-60/93
23		.000071		23	.491555	23	89	1	56-12/93
24		.000642		24	.525325	24	92	54	11-57/93
25		.003491		25	.558978	25	96	46	27- 9/93
26		.008605		26	.592363	26	100	38	42-54/93
27		.015961		27	.625326	27	104	30	58- 6/93
28		.025526		28	.657718	28	108	23	13-51/93
29		.037256		29	.689389	29	112	15	29- 3/93
30		.051098		30	.720197	30	116	7	44-48/93
31		.066987		31	.750000	31	120	00	00000000
32		.084853		32	.778662	32	123	52	15-45/93
33		.104612		33	.806053	33	127	44	30-90/93
34		.126176		34	.832047	34	131	36	46-42/93
35		.149445		35	.856527	35	135	29	1-87/93
36		.174314		36	.879379	36	139	21	17-39/93
37		.200669		37	.900500	37	143	13	32-84/93
38		.228389		38	.919795	38	147	5	48-36/93
39		.257349		39	.937173	39	150	58	3-81/93
40		.287416		40	.952557	40	154	50	19-33/93
41		.318453		41	.965876	41	158	42	34-78/93
42		.350319		42	.977070	42	162	34	50-30/93
43		.382867		43	.986086	43	166	27	5-75/93
44		.415950		44	.992885	44	170	19	21-27/93
45		.449416		45	.997435	45	174	11	36-72/93
46		.483113		46	.999715	46	178	3	52-24/93
47		.516887		47	.999715	47	181	56	7-69/93
48		.550584		48	.997435	48	185	48	23-21/93
49		.584050		49	.992885	49	189	40	38-66/93
50		.617133		50	.986086	50	193	32	54-18/93
51		.649682		51	.977070	51	197	25	9-63/93
52		.681547		52	.965876	52	201	17	25-15/93
53		.712584		53	.952557	53	205	9	40-60/93
54		.742651		54	.937173	54	209	1	56-12/93
55		.771611		55	.919795	55	212	54	11-57/93
56		.799331		56	.900500	56	216	46	27- 9/93
57		.825686		57	.879379	57	220	38	42-54/93
58		.850555		58	.856527	58	224	30	58- 6/93
59		.873824		59	.832047	59	228	23	13-51/93
60		.895388		60	.806053	60	232	15	29- 3/93
61		.915147		61	.778662	61	236	7	44-48/93
62		.933013		62	.750000	62	240	00	00000000
63		.948902		63	.720197	63	243	52	15-45/93
64		.962744		64	.689389	64	247	44	30-90/93
65		.974474		65	.657718	65	251	36	46-42/93
66		.984039		66	.625326	66	255	29	1-87/93
67		.991395		67	.592363	67	259	21	17-39/93
68		.996509		68	.558978	68	263	13	32-84/93
69		.999358		69	.525325	69	267	5	48-36/93
70		.999929		70	.491555	70	270	58	3-81/93
71		.998218		71	.457824	71	274	50	19-33/93
72		.994234		72	.424286	72	278	42	34-78/93
73		.987995		73	.391093	73	282	34	50-30/93
74		.979530		74	.358397	74	286	27	5-75/93
75		.968876		75	.326347	75	290	19	21-27/93
76		.956083		76	.295090	76	294	11	36-72/93
77		.941209		77	.264767	77	298	3	52-24/93
78		.924322		78	.235518	78	301	56	7-69/93
79		.905499		79	.207476	79	305	48	23-21/93
80		.884826		80	.180768	80	309	40	38-66/93
81		.862396		81	.155517	81	313	32	54-18/93
82		.838314		82	.131837	82	317	25	9-63/93
83		.812687		83	.109838	83	321	17	25-15/93
84		.785634		84	.089618	84	325	9	40-60/93
85		.757278		85	.071271	85	329	1	56-12/93
86		.727747		86	.054881	86	332	54	11-57/93
87		.697178		87	.040521	87	336	46	27- 9/93
88		.665709		88	.028258	88	340	38	42-54/93
89		.633484		89	.018147	89	344	30	58- 6/93
90		.600649		90	.010235	90	348	23	13-51/93
91		.567356		91	.004558	91	352	15	29- 3/93
92		.533755		92	.001141	92	356	7	44-48/93
93		.500000		93	.000000	93	360	0	0

# 94 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

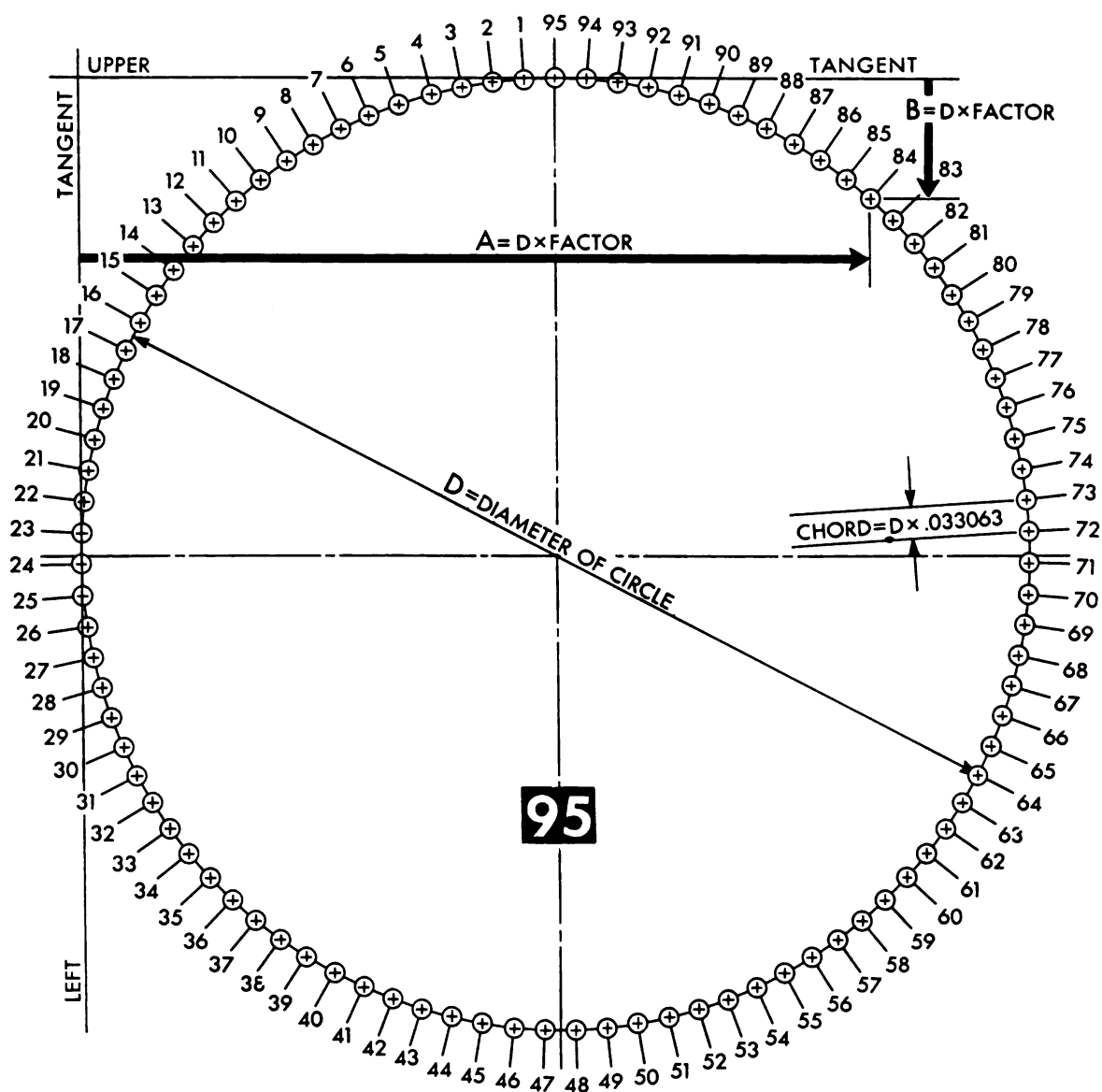


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
1		.466604	1	.001117	1	3	49	47-22/94
2		.433357	2	.004461	2	7	39	34-44/94
3		.400407	3	.010019	3	11	29	21-66/94
4		.367902	4	.017765	4	15	19	8-88/94
5		.335988	5	.027665	5	19	8	56-16/94
6		.304806	6	.039675	6	22	58	43-38/94
7		.274495	7	.053741	7	26	48	30-60/94
8		.245192	8	.069799	8	30	38	17-82/94
9		.217026	9	.087779	9	34	28	5-10/94
10		.190125	10	.107600	10	38	17	52-32/94
11		.164608	11	.129174	11	42	7	39-54/94
12		.140588	12	.152404	12	45	57	26-76/94
13		.118174	13	.177186	13	49	47	14- 4/94
14		.097465	14	.203410	14	53	37	1-26/94
15		.078554	15	.230959	15	57	26	48-48/94
16		.061525	16	.259709	16	61	16	35-70/94
17		.046455	17	.289532	17	65	6	22-92/94
18		.033410	18	.320296	18	68	56	10-20/94
19		.022449	19	.351862	19	72	45	57-42/94

# COORDINATE FACTORS AND ANGLES—94 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
20		.013621	20	.384090	20	76	35	44-64/94
21		.006965	21	.416835	21	80	25	31-86/94
22		.002511	22	.449952	22	84	15	19-14/94
23		.000279	23	.483293	23	88	5	6-36/94
24		.000279	24	.516707	24	91	54	53-58/94
25		.002511	25	.550048	25	95	44	40-80/94
26		.006965	26	.583165	26	99	34	28- 8/94
27		.013621	27	.615910	27	103	24	15-30/94
28		.022449	28	.648138	28	107	14	2-52/94
29		.033410	29	.679704	29	111	3	49-74/94
30		.046455	30	.710468	30	114	53	37- 2/94
31		.061525	31	.740291	31	118	43	24-24/94
32		.078554	32	.769041	32	122	33	11-46/94
33		.097465	33	.796590	33	126	22	58-68/94
34		.118174	34	.822814	34	130	12	45-90/94
35		.140588	35	.847596	35	134	2	33-18/94
36		.164608	36	.870826	36	137	52	20-40/94
37		.190125	37	.892400	37	141	42	7-62/94
38		.217026	38	.912221	38	145	31	54-84/94
39		.245192	39	.930201	39	149	21	42-12/94
40		.274495	40	.946259	40	153	11	29-34/94
41		.304806	41	.960325	41	157	1	16-56/94
42		.335988	42	.972335	42	160	51	3-78/94
43		.367902	43	.982235	43	164	40	51- 6/94
44		.400407	44	.989981	44	168	30	38-28/94
45		.433357	45	.995539	45	172	20	25-50/94
46		.466604	46	.998883	46	176	10	12-72/94
47		.500000	47	1.000000	47	180	00	00000000
48		.533396	48	.998883	48	183	49	47-22/94
49		.566643	49	.995539	49	187	39	34-44/94
50		.599593	50	.989981	50	191	29	21-66/94
51		.632098	51	.982235	51	195	19	8-88/94
52		.664012	52	.972335	52	199	8	56-16/94
53		.695194	53	.960325	53	202	58	43-38/94
54		.725505	54	.946259	54	206	48	30-60/94
55		.754808	55	.930201	55	210	38	17-82/94
56		.782974	56	.912221	56	214	28	5-10/94
57		.809875	57	.892400	57	218	17	52-32/94
58		.835392	58	.870826	58	222	7	39-54/94
59		.859412	59	.847596	59	225	57	26-76/94
60		.881826	60	.822814	60	229	47	14- 4/94
61		.902535	61	.796590	61	233	37	1-26/94
62		.921446	62	.769041	62	237	26	48-48/94
63		.938475	63	.740291	63	241	16	35-70/94
64		.953545	64	.710468	64	245	6	22-92/94
65		.966590	65	.679704	65	248	56	10-20/94
66		.977551	66	.648138	66	252	45	57-42/94
67		.986379	67	.615910	67	256	35	44-64/94
68		.993035	68	.583165	68	260	25	31-86/94
69		.997489	69	.550048	69	264	15	19-14/94
70		.999721	70	.516707	70	268	5	6-36/94
71		.999721	71	.483293	71	271	54	53-58/94
72		.997489	72	.449952	72	275	44	40-80/94
73		.993035	73	.416835	73	279	34	28- 8/94
74		.986379	74	.384090	74	283	24	15-30/94
75		.977551	75	.351862	75	287	14	2-52/94
76		.966590	76	.320296	76	291	3	49-74/94
77		.953545	77	.289532	77	294	53	37- 2/94
78		.938475	78	.259709	78	298	43	24-24/94
79		.921446	79	.230959	79	302	33	11-46/94
80		.902535	80	.203410	80	306	22	58-68/94
81		.881826	81	.177186	81	310	12	45-90/94
82		.859412	82	.152404	82	314	2	33-18/94
83		.835392	83	.129174	83	317	52	20-40/94
84		.809875	84	.107600	84	321	42	7-62/94
85		.782974	85	.087779	85	325	31	54-84/94
86		.754808	86	.069799	86	329	21	42-12/94
87		.725505	87	.053741	87	333	11	29-34/94
88		.695194	88	.039675	88	337	1	16-56/94
89		.664012	89	.027665	89	340	51	3-78/94
90		.632098	90	.017765	90	344	40	51- 6/94
91		.599593	91	.010019	91	348	30	38-28/94
92		.566643	92	.004461	92	352	20	25-50/94
93		.533396	93	.001117	93	356	10	12-72/94
94		.500000	94	.000000	94	360	0	0

# 95 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

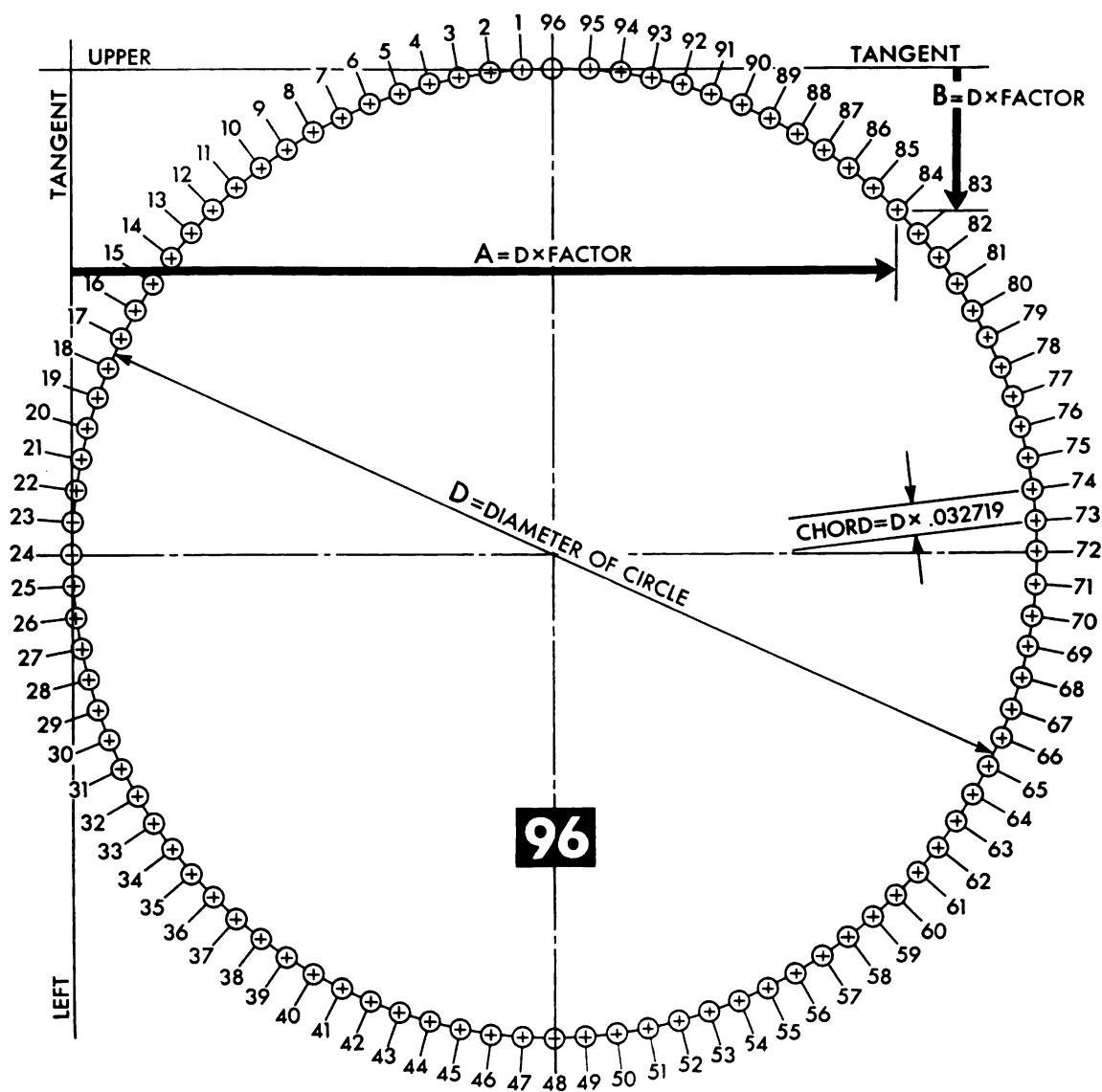


	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
1		.466955	1	.001093	1	3	47	22-10/95	
2		.434054	2	.004368	2	7	34	44-20/95	
3		.401441	3	.009810	3	11	22	6-30/95	
4		.369260	4	.017396	4	15	9	28-40/95	
5		.337650	5	.027091	5	18	56	50-50/95	
6		.306750	6	.038855	6	22	44	12-60/95	
7		.276696	7	.052635	7	26	31	34-70/95	
8		.247617	8	.068372	8	30	18	56-80/95	
9		.219643	9	.085996	9	34	6	18-90/95	
10		.192894	10	.105430	10	37	53	41-5/95	
11		.167488	11	.126589	11	41	41	3-15/95	
12		.143536	12	.149382	12	45	28	25-25/95	
13		.121143	13	.173706	13	49	15	47-35/95	
14		.100406	14	.199459	14	53	3	9-45/95	
15		.081417	15	.226526	15	56	50	31-55/95	
16		.064258	16	.254788	16	60	37	53-65/95	
17		.049004	17	.284123	17	64	25	15-75/95	
18		.035723	18	.314401	18	68	12	37-85/95	
19		.024472	19	.345492	19	72	00	00000000	

# COORDINATE FACTORS AND ANGLES—95 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
20		.015300	20	.377257	20	75	47	22-10/95
21		.008247	21	.409560	21	79	34	44-20/95
22		.003345	22	.442258	22	83	22	6-30/95
23		.000615	23	.475208	23	87	9	28-40/95
24		.000068	24	.508267	24	90	56	50-50/95
25		.001708	25	.541290	25	94	44	12-60/95
26		.005526	26	.574132	26	98	31	34-70/95
27		.011507	27	.606650	27	102	18	56-80/95
28		.019623	28	.638701	28	106	6	18-90/95
29		.029840	29	.670147	29	109	53	41- 5/95
30		.042113	30	.700848	30	113	41	3-15/95
31		.056389	31	.730671	31	117	28	25-25/95
32		.072604	32	.759485	32	121	15	47-35/95
33		.090688	33	.787164	33	125	3	9-45/95
34		.110561	34	.813588	34	128	50	31-55/95
35		.132138	35	.838641	35	132	37	53-65/95
36		.155323	36	.862213	36	136	25	15-75/95
37		.180016	37	.884201	37	140	12	37-85/95
38		.206107	38	.904508	38	144	00	00000000
39		.233484	39	.923048	39	147	47	22-10/95
40		.262026	40	.939737	40	151	34	44-20/95
41		.291609	41	.954503	41	155	22	6-30/95
42		.322103	42	.967282	42	159	9	28-40/95
43		.353375	43	.978018	43	162	56	50-50/95
44		.385289	44	.986663	44	166	44	12-60/95
45		.417702	45	.993181	45	170	31	34-70/95
46		.450478	46	.997541	46	174	18	56-80/95
47		.483468	47	.999727	47	178	6	18-90/95
48		.516532	48	.999727	48	181	53	41- 5/95
49		.549522	49	.997541	49	185	41	3-15/95
50		.582298	50	.993181	50	189	28	25-25/95
51		.614712	51	.986663	51	193	15	47-35/95
52		.646625	52	.978018	52	197	3	9-45/95
53		.677897	53	.967282	53	200	50	31-55/95
54		.708391	54	.954503	54	204	37	53-65/95
55		.737974	55	.939737	55	208	25	15-75/95
56		.766516	56	.923048	56	212	12	37-85/95
57		.793893	57	.904508	57	216	00	00000000
58		.819984	58	.884201	58	219	47	22-10/95
59		.844677	59	.862213	59	223	34	44-20/95
60		.867862	60	.838641	60	227	22	6-30/95
61		.889439	61	.813588	61	231	9	28-40/95
62		.909312	62	.787164	62	234	56	50-50/95
63		.927396	63	.759485	63	238	44	12-60/95
64		.943611	64	.730671	64	242	31	34-70/95
65		.957887	65	.700848	65	246	18	56-80/95
66		.970160	66	.670147	66	250	6	18-90/95
67		.980377	67	.638701	67	253	53	41- 5/95
68		.988493	68	.606650	68	257	41	3-15/95
69		.994474	69	.574132	69	261	28	25-25/95
70		.998292	70	.541290	70	265	15	47-35/95
71		.999932	71	.508267	71	269	3	9-45/95
72		.999385	72	.475208	72	272	50	31-55/95
73		.996655	73	.442258	73	276	37	53-65/95
74		.991753	74	.409560	74	280	25	15-75/95
75		.984700	75	.377257	75	284	12	37-85/95
76		.975528	76	.345492	76	288	00	00000000
77		.964277	77	.314401	77	291	47	22-10/95
78		.950996	78	.284123	78	295	34	44-20/95
79		.935742	79	.254788	79	299	22	6-30/95
80		.918583	80	.226526	80	303	9	28-40/95
81		.899594	81	.199459	81	306	56	50-50/95
82		.878857	82	.173706	82	310	44	12-60/95
83		.856464	83	.149382	83	314	31	34-70/95
84		.832512	84	.126589	84	318	18	56-80/95
85		.807106	85	.105430	85	322	6	18-90/95
86		.780358	86	.085996	86	325	53	41- 5/95
87		.752383	87	.068372	87	329	41	3-15/95
88		.723304	88	.052635	88	333	28	25-25/95
89		.693250	89	.038855	89	337	15	47-35/95
90		.662350	90	.027091	90	341	3	9-45/95
91		.630740	91	.017396	91	344	50	31-55/95
92		.598559	92	.009810	92	348	37	53-65/95
93		.565946	93	.004368	93	352	25	15-75/95
94		.533045	94	.001093	94	356	12	37-85/95
95		.500000	95	.000000	95	360	0	0

# 96 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

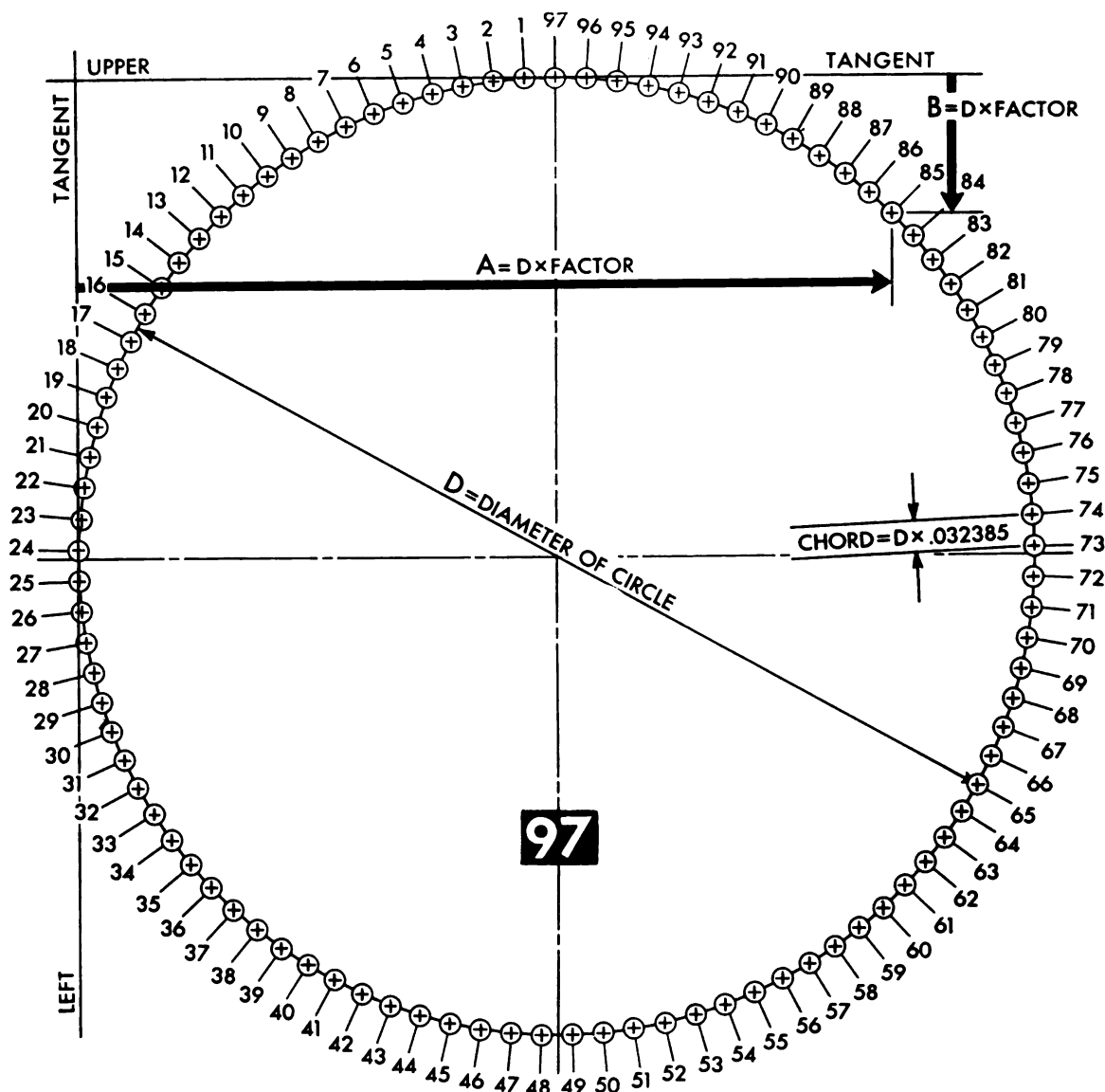


	→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1		.467298	1	.001071	1	3	45
2		.434737	2	.004278	2	7	30
3		.402455	3	.009607	3	11	15
4		.370590	4	.017037	4	15	00
5		.339280	5	.026535	5	18	45
6		.308658	6	.038060	6	22	30
7		.278856	7	.051564	7	26	15
8		.250000	8	.066987	8	30	00
9		.222215	9	.084265	9	33	45
10		.195619	10	.103323	10	37	30
11		.170327	11	.124080	11	41	15
12		.146447	12	.146447	12	45	00
13		.124080	13	.170327	13	48	45
14		.103323	14	.195619	14	52	30
15		.084265	15	.222215	15	56	15
16		.066987	16	.250000	16	60	00
17		.051564	17	.278856	17	63	45
18		.038060	18	.308658	18	67	30
19		.026535	19	.339280	19	71	15
20		.017037	20	.370590	20	75	00

# COORDINATE FACTORS AND ANGLES—96 HOLE DIVISION

➔	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE			
				DEG.	MIN.	SEC.	
21	.009607	21	.402455	21	78	45	0
22	.004278	22	.434737	22	82	30	0
23	.001071	23	.467298	23	86	15	0
24	.000000	24	.500000	24	90	00	0
25	.001071	25	.532702	25	93	45	0
26	.004278	26	.565263	26	97	30	0
27	.009607	27	.597545	27	101	15	0
28	.017037	28	.629410	28	105	00	0
29	.026535	29	.660720	29	108	45	0
30	.038060	30	.691342	30	112	30	0
31	.051564	31	.721144	31	116	15	0
32	.066987	32	.750000	32	120	00	0
33	.084265	33	.777785	33	123	45	0
34	.103323	34	.804381	34	127	30	0
35	.124080	35	.829673	35	131	15	0
36	.146447	36	.853553	36	135	00	0
37	.170327	37	.875920	37	138	45	0
38	.195619	38	.896677	38	142	30	0
39	.222215	39	.915735	39	146	15	0
40	.250000	40	.933013	40	150	00	0
41	.278856	41	.948436	41	153	45	0
42	.308658	42	.961940	42	157	30	0
43	.339280	43	.973465	43	161	15	0
44	.370590	44	.982963	44	165	00	0
45	.402455	45	.990393	45	168	45	0
46	.434737	46	.995722	46	172	30	0
47	.467298	47	.998929	47	176	15	0
48	.500000	48	1.000000	48	180	00	0
49	.532702	49	.998929	49	183	45	0
50	.565263	50	.995722	50	187	30	0
51	.597545	51	.990393	51	191	15	0
52	.629410	52	.982963	52	195	00	0
53	.660720	53	.973465	53	198	45	0
54	.691342	54	.961940	54	202	30	0
55	.721144	55	.948436	55	206	15	0
56	.750000	56	.933013	56	210	00	0
57	.777785	57	.915735	57	213	45	0
58	.804381	58	.896677	58	217	30	0
59	.829673	59	.875920	59	221	15	0
60	.853553	60	.853553	60	225	00	0
61	.875920	61	.829673	61	228	45	0
62	.896677	62	.804381	62	232	30	0
63	.915735	63	.777785	63	236	15	0
64	.933013	64	.750000	64	240	00	0
65	.948436	65	.721144	65	243	45	0
66	.961940	66	.691342	66	247	30	0
67	.973465	67	.660720	67	251	15	0
68	.982963	68	.629410	68	255	00	0
69	.990393	69	.597545	69	258	45	0
70	.995722	70	.565263	70	262	30	0
71	.998929	71	.532702	71	266	15	0
72	1.000000	72	.500000	72	270	00	0
73	.998929	73	.467298	73	273	45	0
74	.995722	74	.434737	74	277	30	0
75	.990393	75	.402455	75	281	15	0
76	.982963	76	.370590	76	285	00	0
77	.973465	77	.339280	77	288	45	0
78	.961940	78	.308658	78	292	30	0
79	.948436	79	.278856	79	296	15	0
80	.933013	80	.250000	80	300	00	0
81	.915735	81	.222215	81	303	45	0
82	.896677	82	.195619	82	307	30	0
83	.875920	83	.170327	83	311	15	0
84	.853553	84	.146447	84	315	00	0
85	.829673	85	.124080	85	318	45	0
86	.804381	86	.103323	86	322	30	0
87	.777785	87	.084265	87	326	15	0
88	.750000	88	.066987	88	330	00	0
89	.721144	89	.051564	89	333	45	0
90	.691342	90	.038060	90	337	30	0
91	.660720	91	.026535	91	341	15	0
92	.629410	92	.017037	92	345	00	0
93	.597545	93	.009607	93	348	45	0
94	.565263	94	.004278	94	352	30	0
95	.532702	95	.001071	95	356	15	0
96	.500000	96	.000000	96	360	0	0

# 97 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

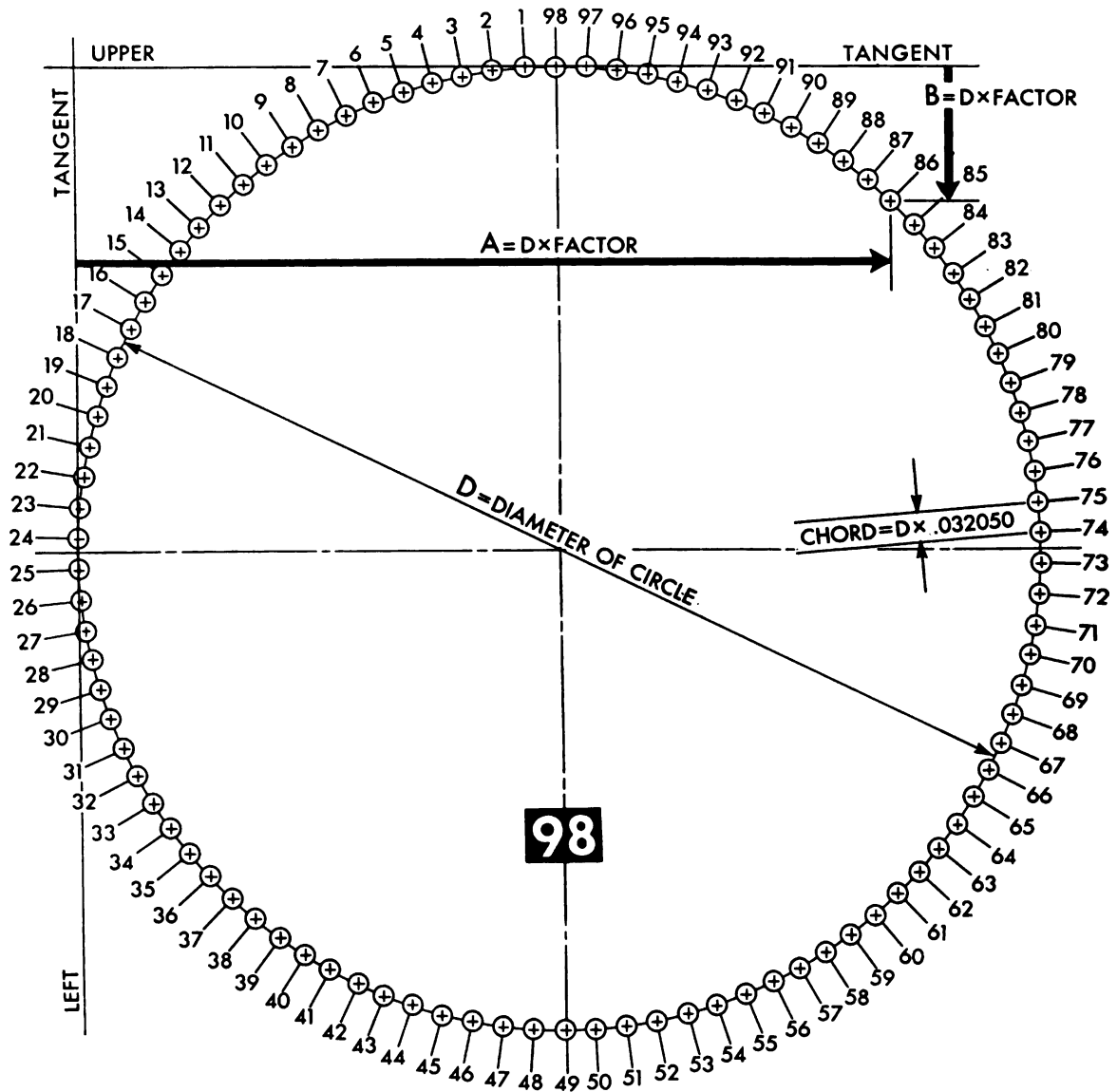


	→	FACTOR FOR "A"		FACTOR FOR "B"	↓		ANGLE OF HOLE		
							DEG.	MIN.	SEC.
1		.467635	1		.001049	1	3	42	40-80/97
2		.435406	2		.004190	2	7	25	21-63/97
3		.403448	3		.009411	3	11	8	2-46/97
4		.371894	4		.016690	4	14	50	43-29/97
5		.340879	5		.025995	5	18	33	24-12/97
6		.310530	6		.037289	6	22	16	4-92/97
7		.280976	7		.050524	7	25	58	45-75/97
8		.252341	8		.065644	8	29	41	26-58/97
9		.224745	9		.082586	9	33	24	7-41/97
10		.198303	10		.101278	10	37	6	48-24/97
11		.173126	11		.121644	11	40	49	29-7/97
12		.149321	12		.143596	12	44	32	9-87/97
13		.126986	13		.167042	13	48	14	50-70/97
14		.106216	14		.191886	14	51	57	31-53/97
15		.087098	15		.218021	15	55	40	12-36/97
16		.069711	16		.245340	16	59	22	53-19/97
17		.054130	17		.273726	17	63	5	34-2/97
18		.040418	18		.303062	18	66	48	14-82/97
19		.028634	19		.333224	19	70	30	55-65/97
20		.018827	20		.364085	20	74	13	36-48/97

# COORDINATE FACTORS AND ANGLES—97 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
21		.011039		21	.395516	77	56	17-31/97
22		.005301		22	.427386	81	38	58-14/97
23		.001638		23	.459560	85	21	38-94/97
24		.000066		24	.491903	89	4	19-77/97
25		.000590		25	.524281	92	47	00-60/97
26		.003209		26	.556557	96	29	41-43/97
27		.007912		27	.588596	100	12	22-26/97
28		.014679		28	.620262	103	55	3- 9/97
29		.023481		29	.651425	107	37	43-89/97
30		.034282		30	.681952	111	20	24-72/97
31		.047036		31	.711717	115	3	5-55/97
32		.061691		32	.740593	118	45	46-38/97
33		.078183		33	.768460	122	28	27-21/97
34		.096445		34	.795201	126	11	8- 4/97
35		.116400		35	.820704	129	53	48-84/97
36		.137964		36	.844862	133	36	29-67/97
37		.161046		37	.867573	137	19	10-50/97
38		.185550		38	.888743	141	1	51-33/97
39		.211372		39	.908282	144	44	32-16/97
40		.238405		40	.926108	148	27	12-96/97
41		.266536		41	.942148	152	9	53-79/97
42		.295646		42	.956333	155	52	34-62/97
43		.325613		43	.968603	159	35	15-45/97
44		.356311		44	.978909	163	17	56-28/97
45		.387612		45	.987205	167	00	37-11/97
46		.419385		46	.993458	170	43	17-91/97
47		.451495		47	.997642	174	25	58-74/97
48		.483809		48	.999738	178	8	39-57/97
49		.516191		49	.999738	181	51	20-40/97
50		.548505		50	.997642	185	34	1-23/97
51		.580615		51	.993458	189	16	42- 6/97
52		.612388		52	.987205	192	59	22-86/97
53		.643689		53	.978909	196	42	3-69/97
54		.674387		54	.968603	200	24	44-52/97
55		.704354		55	.956333	204	7	25-35/97
56		.733464		56	.942148	207	50	6-18/97
57		.761595		57	.926108	211	32	47- 1/97
58		.788628		58	.908282	215	15	27-81/97
59		.814450		59	.888743	218	58	8-64/97
60		.838954		60	.867573	222	40	49-47/97
61		.862036		61	.844862	226	23	30-30/97
62		.883600		62	.820704	230	6	11-13/97
63		.903555		63	.795201	233	48	51-93/97
64		.921817		64	.768460	237	31	32-76/97
65		.938309		65	.740593	241	14	13-59/97
66		.952964		66	.711717	244	56	54-42/97
67		.965718		67	.681952	248	39	35-25/97
68		.976519		68	.651425	252	22	16- 8/97
69		.985321		69	.620262	256	4	56-88/97
70		.992088		70	.588596	259	47	37-71/97
71		.996791		71	.556557	263	30	18-54/97
72		.999410		72	.524281	267	12	59-37/97
73		.999934		73	.491903	270	55	40-20/97
74		.998362		74	.459560	274	38	21- 3/97
75		.994699		75	.427386	278	21	1-83/97
76		.988961		76	.395516	282	3	42-66/97
77		.981173		77	.364085	285	46	23-49/97
78		.971366		78	.333224	289	29	4-32/97
79		.959582		79	.303062	293	11	45-15/97
80		.945870		80	.273726	296	54	25-95/97
81		.930289		81	.245340	300	37	6-78/97
82		.912902		82	.218021	304	19	47-61/97
83		.893784		83	.191886	308	2	28-44/97
84		.873014		84	.167042	311	45	9-27/97
85		.850679		85	.143596	315	27	50-10/97
86		.826874		86	.121644	319	10	30-90/97
87		.801697		87	.101278	322	53	11-73/97
88		.775255		88	.082586	326	35	52-56/97
89		.747659		89	.065644	330	18	33-39/97
90		.719024		90	.050524	334	1	14-22/97
91		.689470		91	.037289	337	43	55- 5/97
92		.659121		92	.025995	341	26	35-85/97
93		.628106		93	.016690	345	9	16-68/97
94		.596552		94	.009411	348	51	57-51/97
95		.564594		95	.004190	352	34	38-34/97
96		.532365		96	.001049	356	17	19-17/97
97		.500000		97	.000000	360	0	0

# 98 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

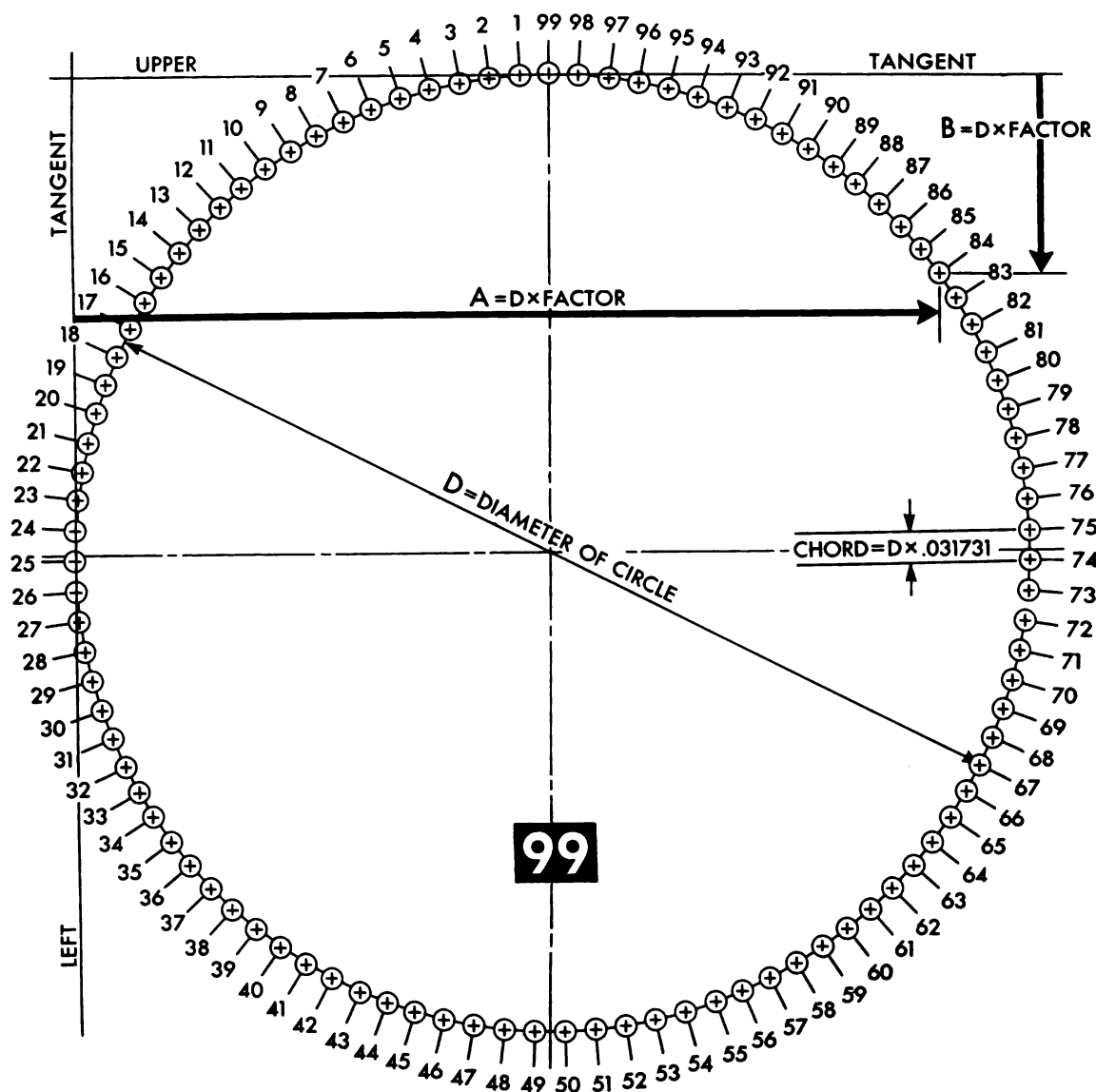


	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.467965	1	.001027	1	3	40	24-48/98
2	.436061	2	.004105	2	7	20	48-96/98
3	.404421	3	.009220	3	11	1	13-46/98
4	.373175	4	.016353	4	14	41	37-94/98
5	.342447	5	.025472	5	18	22	2-44/98
6	.312367	6	.036542	6	22	2	26-92/98
7	.283058	7	.049516	7	25	42	51-42/98
8	.254641	8	.064341	8	29	23	15-90/98
9	.227233	9	.080956	9	33	3	40-40/98
10	.200945	10	.099293	10	36	44	4-88/98
11	.175886	11	.119277	11	40	24	29-38/98
12	.152159	12	.140825	12	44	4	53-86/98
13	.129860	13	.163850	13	47	45	18-36/98
14	.109084	14	.188255	14	51	25	42-84/98
15	.089914	15	.213942	15	55	6	7-34/98
16	.072429	16	.240804	16	58	46	31-82/98
17	.056700	17	.268731	17	62	26	56-32/98
18	.042794	18	.297608	18	66	7	20-80/98
19	.030766	19	.327318	19	69	47	45-30/98
20	.020666	20	.357736	20	73	28	9-78/98

# COORDINATE FACTORS AND ANGLES—98 HOLE DIVISION

	→	FACTOR FOR "A"		FACTOR FOR "B"	↓	ANGLE OF HOLE		
						DEG.	MIN.	SEC.
21		.012536	21	.388740	21	77	8	34-28/98
22		.006409	22	.420200	22	80	48	58-76/98
23		.002310	23	.451988	23	84	29	23-26/98
24		.000257	24	.483972	24	88	9	47-74/98
25		.000257	25	.516028	25	91	50	12-24/98
26		.002310	26	.548012	26	95	30	36-72/98
27		.006409	27	.579800	27	99	11	1-22/98
28		.012536	28	.611260	28	102	51	25-70/98
29		.020666	29	.642264	29	106	31	50-20/98
30		.030766	30	.672682	30	110	12	14-68/98
31		.042794	31	.702392	31	113	52	39-18/98
32		.056700	32	.731269	32	117	33	3-66/98
33		.072429	33	.759196	33	121	13	28-16/98
34		.089914	34	.786058	34	124	53	52-64/98
35		.109084	35	.811745	35	128	34	17-14/98
36		.129861	36	.836150	36	132	14	41-62/98
37		.152159	37	.859175	37	135	55	6-12/98
38		.175886	38	.880723	38	139	35	30-60/98
39		.200945	39	.900707	39	143	15	55-10/98
40		.227233	40	.919044	40	146	56	19-58/98
41		.254641	41	.935659	41	150	36	44- 8/98
42		.283058	42	.950484	42	154	17	8-56/98
43		.312367	43	.963458	43	157	57	33- 6/98
44		.342447	44	.974528	44	161	37	57-54/98
45		.373175	45	.983647	45	165	18	22- 4/98
46		.404421	46	.990780	46	168	58	46-52/98
47		.436061	47	.995895	47	172	39	11- 2/98
48		.467965	48	.998973	48	176	19	35-50/98
49		.500000	49	1.000000	49	180	00	00000000
50		.532035	50	.998973	50	183	40	24-48/98
51		.563939	51	.995895	51	187	20	48-96/98
52		.595579	52	.990780	52	191	1	13-46/98
53		.626825	53	.983647	53	194	41	37-94/98
54		.657553	54	.974528	54	198	22	2-44/98
55		.687634	55	.963458	55	202	2	26-92/98
56		.716942	56	.950484	56	205	42	51-42/98
57		.745359	57	.935659	57	209	23	15-90/98
58		.772767	58	.919044	58	213	3	40-40/98
59		.799055	59	.900707	59	216	44	4-88/98
60		.824114	60	.880723	60	220	24	29-38/98
61		.847841	61	.859175	61	224	4	53-86/98
62		.870139	62	.836150	62	227	45	18-36/98
63		.890916	63	.811745	63	231	25	42-84/98
64		.910086	64	.786058	64	235	6	7-34/98
65		.927571	65	.759196	65	238	46	31-82/98
66		.943300	66	.731269	66	242	26	56-32/98
67		.957206	67	.702392	67	246	7	20-80/98
68		.969234	68	.672682	68	249	47	45-30/98
69		.979334	69	.642264	69	253	28	9-78/98
70		.987464	70	.611260	70	257	8	34-28/98
71		.993591	71	.579800	71	260	48	58-76/98
72		.997690	72	.548012	72	264	29	23-26/98
73		.999743	73	.516028	73	268	9	47-74/98
74		.999743	74	.483972	74	271	50	12-24/98
75		.997690	75	.451988	75	275	30	36-72/98
76		.993591	76	.420200	76	279	11	1-22/98
77		.987464	77	.388740	77	282	51	25-70/98
78		.979334	78	.357736	78	286	31	50-20/98
79		.969234	79	.327318	79	290	12	14-68/98
80		.957206	80	.297608	80	293	52	39-18/98
81		.943300	81	.268731	81	297	33	3-66/98
82		.927571	82	.240804	82	301	13	28-16/98
83		.910086	83	.213942	83	304	53	52-64/98
84		.890916	84	.188255	84	308	34	17-14/98
85		.870139	85	.163850	85	312	14	41-62/98
86		.847841	86	.140825	86	315	55	6-12/98
87		.824114	87	.119277	87	319	35	30-60/98
88		.799055	88	.099293	88	323	15	55-10/98
89		.772767	89	.080956	89	326	56	19-58/98
90		.745359	90	.064341	90	330	36	44- 8/98
91		.716942	91	.049516	91	334	17	8-56/98
92		.687634	92	.036542	92	337	57	33- 6/98
93		.657553	93	.025472	93	341	37	57-54/98
94		.626825	94	.016353	94	345	18	22- 4/98
95		.595579	95	.009220	95	348	58	46-52/98
96		.563939	96	.004105	96	352	39	11- 2/98
97		.532035	97	.001027	97	356	19	35-50/98
98		.500000	98	.000000	98	360	0	0

# 99 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



	FACTOR FOR "A"	FACTOR FOR "B"			ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.468290	1	.001007	1	3	38	10-90/99
2	.436704	2	.004023	2	7	16	21-81/99
3	.405374	3	.009036	3	10	54	32-72/99
4	.374426	4	.016026	4	14	32	43-63/99
5	.343983	5	.024964	5	18	10	54-54/99
6	.314169	6	.035816	6	21	49	5-45/99
7	.285103	7	.048537	7	25	27	16-36/99
8	.256902	8	.063075	8	29	5	27-27/99
9	.229680	9	.079373	9	32	43	38-18/99
10	.203546	10	.097365	10	36	21	49-9/99
11	.178606	11	.116978	11	40	00	00000000
12	.154961	12	.138133	12	43	38	10-90/99
13	.132704	13	.160745	13	47	16	21-81/99
14	.111927	14	.184724	14	50	54	32-72/99
15	.092712	15	.209972	15	54	32	43-63/99
16	.075138	16	.236387	16	58	10	54-54/99
17	.059273	17	.263864	17	61	49	5-45/99
18	.045184	18	.292292	18	65	27	16-36/99
19	.032926	19	.321557	19	69	5	27-27/99
20	.022549	20	.351540	20	72	43	38-18/99

# COORDINATE FACTORS AND ANGLES—99 HOLE DIVISION

	→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
						DEG.	MIN.	SEC.
21		.014094	21	.382121	21	76	21	49- 9/99
22		.007596	22	.413176	22	80	00	00000000
23		.003081	23	.444581	23	83	38	10-90/99
24		.000566	24	.476209	24	87	16	21-81/99
25		.000063	25	.507933	25	90	54	32-72/99
26		.001573	26	.539625	26	94	32	43-63/99
27		.005089	27	.571157	27	98	10	54-54/99
28		.010599	28	.602403	28	101	49	5-45/99
29		.018079	29	.633237	29	105	27	16-36/99
30		.027500	30	.663534	30	109	5	27-27/99
31		.038823	31	.693173	31	112	43	38-18/99
32		.052003	32	.722033	32	116	21	49- 9/99
33		.066987	33	.750000	33	120	00	00000000
34		.083715	34	.776960	34	123	38	10-90/99
35		.102119	35	.802805	35	127	16	21-81/99
36		.122125	36	.827430	36	130	54	32-72/99
37		.143653	37	.850737	37	134	32	43-63/99
38		.166616	38	.872632	38	138	10	54-54/99
39		.190921	39	.893027	39	141	49	5-45/99
40		.216470	40	.911838	40	145	27	16-36/99
41		.243161	41	.928992	41	149	5	27-27/99
42		.270887	42	.944418	42	152	43	38-18/99
43		.299535	43	.958054	43	156	21	49- 9/99
44		.328990	44	.969846	44	160	00	00000000
45		.359134	45	.979746	45	163	38	10-90/99
46		.389845	46	.987715	46	167	16	21-81/99
47		.420999	47	.993719	47	170	54	32-72/99
48		.452472	48	.997736	48	174	32	43-63/99
49		.484136	49	.999748	49	178	10	54-54/99
50		.515864	50	.999748	50	181	49	5-45/99
51		.547528	51	.997736	51	185	27	16-36/99
52		.579001	52	.993719	52	189	5	27-27/99
53		.610155	53	.987715	53	192	43	38-18/99
54		.640866	54	.979746	54	196	21	49- 9/99
55		.671010	55	.969846	55	200	00	00000000
56		.700465	56	.958054	56	203	38	10-90/99
57		.729113	57	.944418	57	207	16	21-81/99
58		.756839	58	.928992	58	210	54	32-72/99
59		.783530	59	.911839	59	214	32	43-63/99
60		.809080	60	.893027	60	218	10	54-54/99
61		.833385	61	.872632	61	221	49	5-45/99
62		.856347	62	.850737	62	225	27	16-36/99
63		.877875	63	.827430	63	229	5	27-27/99
64		.897881	64	.802805	64	232	43	38-18/99
65		.916285	65	.776960	65	236	21	49- 9/99
66		.933013	66	.750000	66	240	00	00000000
67		.947997	67	.722033	67	243	38	10-90/99
68		.961177	68	.693173	68	247	16	21-81/99
69		.972500	69	.663534	69	250	54	32-72/99
70		.981921	70	.633237	70	254	32	43-63/99
71		.989401	71	.602403	71	258	10	54-54/99
72		.994911	72	.571157	72	261	49	5-45/99
73		.998427	73	.539625	73	265	27	16-36/99
74		.999937	74	.507933	74	269	5	27-27/99
75		.999434	75	.476209	75	272	43	38-18/99
76		.996919	76	.444581	76	276	21	49- 9/99
77		.992404	77	.413176	77	280	00	00000000
78		.985906	78	.382121	78	283	38	10-90/99
79		.977451	79	.351540	79	287	16	21-81/99
80		.967074	80	.321557	80	290	54	32-72/99
81		.954816	81	.292292	81	294	32	43-63/99
82		.940727	82	.263864	82	298	10	54-54/99
83		.924862	83	.236387	83	301	49	5-45/99
84		.907288	84	.209972	84	305	27	16-36/99
85		.888073	85	.184724	85	309	5	27-27/99
86		.867296	86	.160745	86	312	43	38-18/99
87		.845039	87	.138133	87	316	21	49- 9/99
88		.821394	88	.116978	88	320	00	00000000
89		.796454	89	.097365	89	323	38	10-90/99
90		.770320	90	.079373	90	327	16	21-81/99
91		.743098	91	.063075	91	330	54	32-72/99
92		.714897	92	.048537	92	334	32	43-63/99
93		.685831	93	.035816	93	338	10	54-54/99
94		.656017	94	.024964	94	341	49	5-45/99
95		.625574	95	.016026	95	345	27	16-36/99
96		.594626	96	.009036	96	349	5	27-27/99
97		.563296	97	.004023	97	352	43	38-18/99
98		.531710	98	.001007	98	356	21	49- 9/99
99		.500000	99	.000000	99	360	0	0

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# COORDINATE FACTORS AND ANGLES—100 HOLE DIVISION

	➔	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE			
					DEG.	MIN.	SEC.	
21		.015708	21	.375655	21	75	36	0
22		.008856	22	.406309	22	79	12	0
23		.003943	23	.437333	23	82	48	0
24		.000987	24	.468605	24	86	24	0
25		.000000	25	.500000	25	90	00	0
26		.000987	26	.531395	26	93	36	0
27		.003943	27	.562667	27	97	12	0
28		.008856	28	.593691	28	100	48	0
29		.015708	29	.624345	29	104	24	0
30		.024472	30	.654508	30	108	00	0
31		.035112	31	.684062	31	111	36	0
32		.047586	32	.712890	32	115	12	0
33		.061847	33	.740877	33	118	48	0
34		.077836	34	.767913	34	122	24	0
35		.095492	35	.793893	35	126	00	0
36		.114743	36	.818712	36	129	36	0
37		.135516	37	.842274	37	133	12	0
38		.157726	38	.864484	38	136	48	0
39		.181288	39	.885257	39	140	24	0
40		.206107	40	.904508	40	144	00	0
41		.232087	41	.922164	41	147	36	0
42		.259123	42	.938153	42	151	12	0
43		.287110	43	.952414	43	154	48	0
44		.315937	44	.964888	44	158	24	0
45		.345492	45	.975528	45	162	00	0
46		.375655	46	.984292	46	165	36	0
47		.406309	47	.991144	47	169	12	0
48		.437333	48	.996057	48	172	48	0
49		.468605	49	.999013	49	176	24	0
50		.500000	50	1.000000	50	180	00	0
51		.531395	51	.999013	51	183	36	0
52		.562667	52	.996057	52	187	12	0
53		.593691	53	.991144	53	190	48	0
54		.624345	54	.984292	54	194	24	0
55		.654508	55	.975528	55	198	00	0
56		.684062	56	.964888	56	201	36	0
57		.712890	57	.952414	57	205	12	0
58		.740877	58	.938153	58	208	48	0
59		.767913	59	.922164	59	212	24	0
60		.793893	60	.904508	60	216	00	0
61		.818712	61	.885257	61	219	36	0
62		.842274	62	.864484	62	223	12	0
63		.864484	63	.842274	63	226	48	0
64		.885257	64	.818712	64	230	24	0
65		.904508	65	.793893	65	234	00	0
66		.922164	66	.767913	66	237	36	0
67		.938153	67	.740877	67	241	12	0
68		.952414	68	.712890	68	244	48	0
69		.964888	69	.684062	69	248	24	0
70		.975528	70	.654508	70	252	00	0
71		.984292	71	.624345	71	255	36	0
72		.991144	72	.593691	72	259	12	0
73		.996057	73	.562667	73	262	48	0
74		.999013	74	.531395	74	266	24	0
75		1.000000	75	.500000	75	270	00	0
76		.999013	76	.468605	76	273	36	0
77		.996057	77	.437333	77	277	12	0
78		.991144	78	.406309	78	280	48	0
79		.984292	79	.375655	79	284	24	0
80		.975528	80	.345492	80	288	00	0
81		.964888	81	.315937	81	291	36	0
82		.952414	82	.287110	82	295	12	0
83		.938153	83	.259123	83	298	48	0
84		.922164	84	.232087	84	302	24	0
85		.904508	85	.206107	85	306	00	0
86		.885257	86	.181288	86	309	36	0
87		.864484	87	.157726	87	313	12	0
88		.842274	88	.135516	88	316	48	0
89		.818712	89	.114743	89	320	24	0
90		.793893	90	.095492	90	324	00	0
91		.767913	91	.077836	91	327	36	0
92		.740877	92	.061847	92	331	12	0
93		.712890	93	.047586	93	334	48	0
94		.684062	94	.035112	94	338	24	0
95		.654508	95	.024472	95	342	00	0
96		.624345	96	.015708	96	345	36	0
97		.593691	97	.008856	97	349	12	0
98		.562667	98	.003943	98	352	48	0
99		.531395	99	.000987	99	356	24	0
100		.500000	100	.000000	100	360	0	0



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